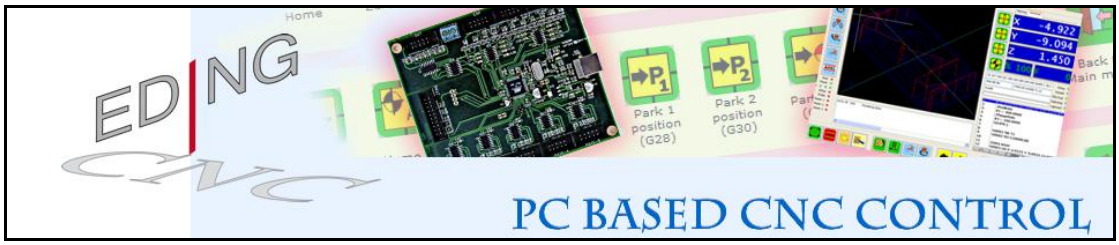

USB CNC
software & interface

USBCNC

User Manual

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1.06	2006-09-05	Bert Eding	Added setup parameter A-Axis Linear
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3.02	2008-04-12	Bert Eding	Implemented line simplification, merges small G1's to one bigger with specified accuracy.

			The same accuracy is also used in the blending algorithm. Partially blending instead of full blending now possible. The behavior is similar to that of the EMC2 project, however, I have implemented this myself in the EMC1 interpreter and also implemented a new modified trajectory generator. Next step will be Look Ahead Feed, later. See chapter: Set Path Control Mode - G61, and G64, or G64 Px
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3.34	2009-2-1	Bert Eding	Added JOGPAD description and G41.1/G41.2 plus examples.
3.36	2009-2-12	Bert Eding	Added more description to LAF.

3.42	2009-09-20	Bert Eding	Added G33, G76 for turning. Note that turning required special firmware. Contact me if you want to do turning.
3.42.1	2009-09-20	Bert Eding	Modified some textual mistakes.
3.43	2009-09-20	Bert Eding	New USB drivers, compatible with XP, VISTA and Windows 7
3.44	2009-11-14	Bert Eding	Updated thread cutting + driver installation
3.46	2010-01-03	Bert Eding	Updated thread cutting + driver installation
3.47	2010-01-10	Bert Eding	Updated driver installation
3.48	2010-01-11	Bert Eding	Updated driver installation for 64 Bit Windows

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The G-Code part of this user manual has been derived from the full report of the RS274/NGC language. Parts that are less relevant to USBCNC users or parts that are not supported are left out. The original report has the following title:

The NIST RS274NGC Interpreter -Version 3

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NISTIR 6556August 17, 2000

On the issue date of this user manual (020225) the report was available on the World Wide Web using the URL:

http://www.linuxcnc.org/handbook/RS274NGC_3/RS274NGC_3TOC.html

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1 Introduction

This user manual is intended to be useful to machine operators running machining centers with USBCNC. USBCNC uses the RS274/NGC interpreter of the EMC project before it was GPLed.

The RS274/NGC Interpreter (the Interpreter) is a software system that reads numerical control code in the "NGC" (Next Generation Controller) dialect of the RS274 numerical control language.

I extended the language with constructs that allow programming inside the language, see the language extensions chapter.

1.1 BACKGROUND

1.1.1 Machine context for USBCNC

1.1.1.1 USBCNC HARDWARE

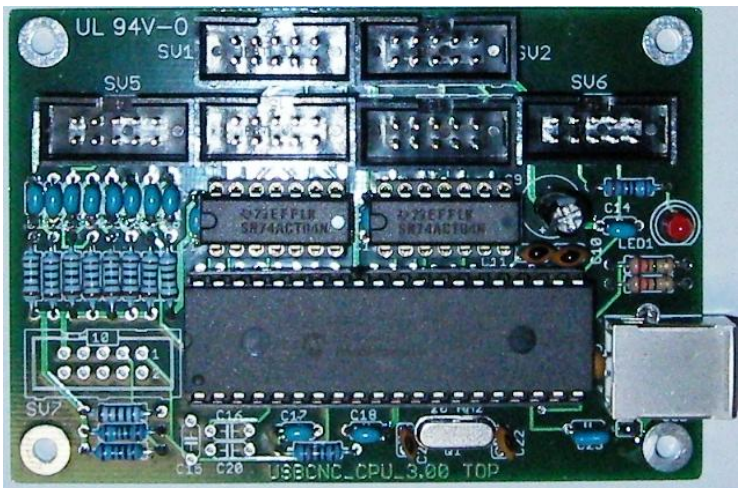
USBCNC_CPU_3

- **4 Layer design, better EMC compatible**
- **All step/direction/amp-enable signals buffered**
- **Separate EOS inputs for each axis**
- **Run/Pause input**
- **More outputs including PWM**
- **PICSTEP compatible**

SV2-1 : AMP-ENABLE
SV2-3 : DIR-X
SV2-5 : STEP-X
SV2-9 : +5 USB
SV2-2,
SV2-4,
SV2-6,
SV2-7,
SV2-10 : GND USB

SV4 : Idem for Y-Axis
SV1 : Idem for Z-Axis
SV3 : Idem for A-Axis

SV5-1 : EOS-X
SV5-3 : EOS-Y
SV5-5 : EOS-Z
SV5-7 : EOS-A
SV5-9 : +5 USB
SV5-2 : ESTOP
SV5-4 : PROBE



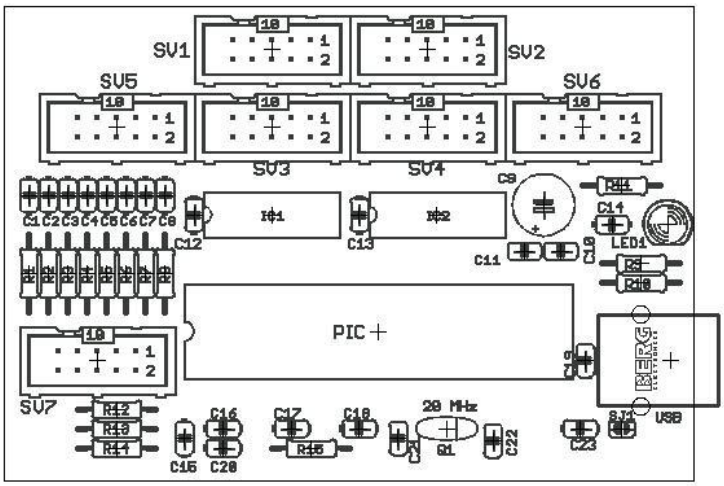
SV5-6 : Pause
SV5-8 : Run
SV5-10 : GND USB

SV6-1 : Tool
SV6-3 : Flood
SV6-5 : MIST
SV6-7 : MACHON
SV6-9 : +5 USB

SV6-2 : PWM-ON
SV6-4 : PWM
SV6-6 : AUX1
SV6-8 : N.C.
SV6-10: GND USB

SV-7 : Not Used

Connect unused inputs to GND.

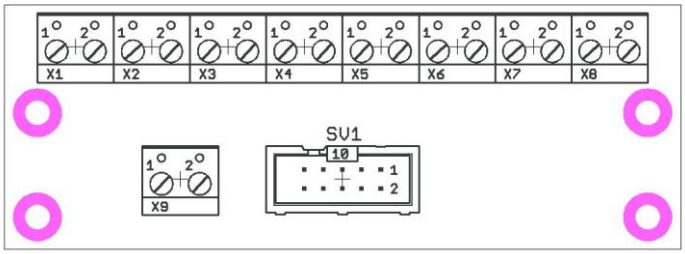


I/O characteristics of USBCNC_CPU_3

- All outputs can individually source or sink 24 mA. (Connect mains solid state relays here).
- Inputs can be a simple switch that connects to the signal and GND

The PWM output generates a PWM signal with a frequency of 5 KHz.
The duty cycle is fully adjustable from 0 – 100%

Building: Just solder all parts, starting with the smaller ones. Don't forget to connect SJ1.

I/O Breakout board for USBCNC_CPU_3	
X1-1: SV1-1 (TOOL, EOS-X) X2-1: SV1-3 (FLOOD, EOS-Y) X3-1: SV1-5 (MIST, EOS-Z) X4-1: SV1-7 (MACHON, EOS-A) X5-1: SV1-2 (PWMON, ESTOP) X6-1: SV1-4 (PWM, PROBE) X7-1: SV1-6 (AUX1, PAUSE) X8-1: SV1-8 (-, RUN) X9-1: SV1-9 (+5 USB) X9-2: SV1-10 (GND USB) X1-2 .. X8-2: GND USB	
This board may be handy to connect your outputs or inputs. You can also build a board yourself that fits your CNC system).	

USBCNC_CPU_4

- **4 Layer design**
- **5 Axes**
- **75 KHz step frequency**
- **All I/O signals buffered and filtered**
- **Run/Pause input**
- **PWM**
- **Hand wheel input**
- **PICSTEP compatible connectors, same as previous CPU's**

AXIS-X-1: AMP-ENABLE
AXIS-X-2: GND
AXIS-X-3: DIR-X
AXIS-X-4: GND
AXIS-X-5: STEP-X
AXIS-X-6: GND
AXIS-X-7: GND
AXIS-X-8: GND
AXIS-X-9: +5 USB
AXIS-X-10: GND

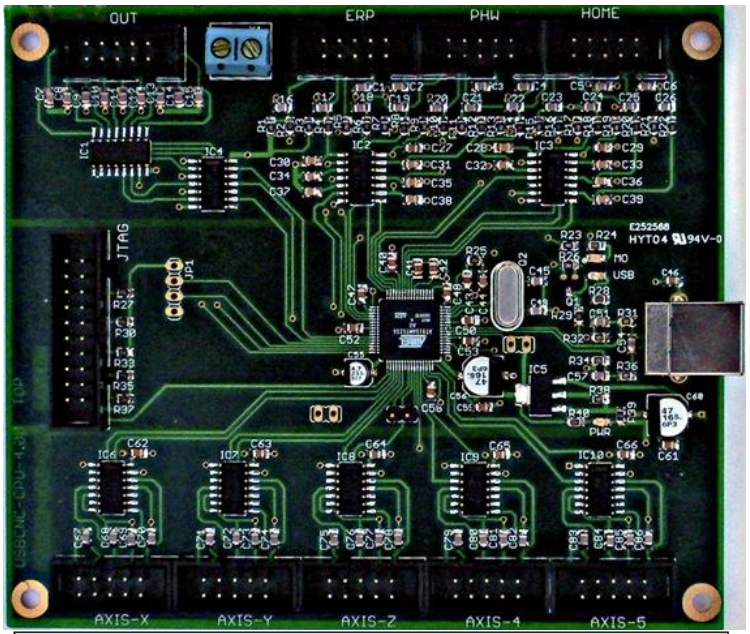
AXIS-Y : Idem for Y-Axis
AXIS-Z : Idem for Z-Axis
AXIS-4 : Idem for A-Axis
AXIS-5 : Idem for B-Axis

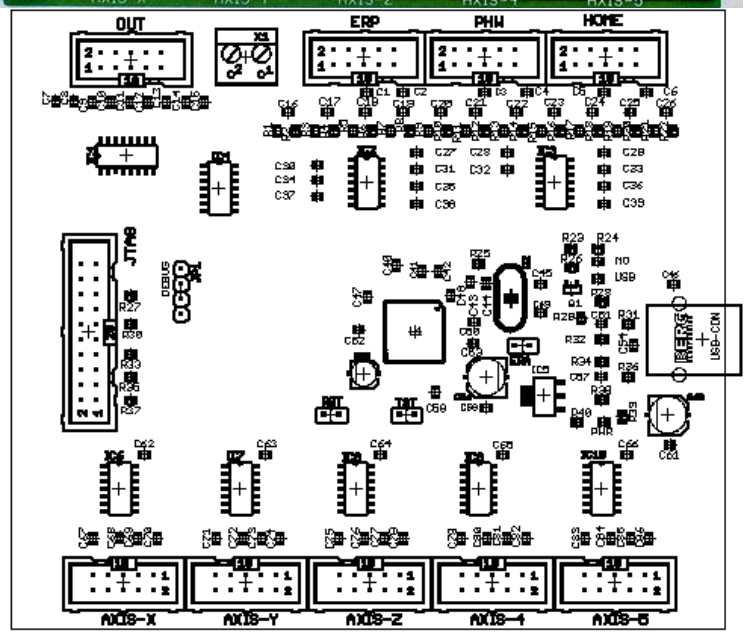
HOME-1 : X home switch
HOME-2 : A home switch
HOME-3 : Y home switch
HOME-4 : B home switch
(For lathe firmware, the spindle pulse sensor is connected here)

HOME-5 : Z home switch
HOME-6 : GND
HOME-7 : +V-EXT
HOME-8 : GND
HOME-9 : +5 USB
HOME-10 : GND

PHW-1: Probe input
PHW-2: GND
PHW-3: HANDWHEEL-A
PHW-4: GND
PHW-5: HANDWHEEL-B
PHW-6: GND
PHW-7: +V-Ext
PHW-8: GND
PHW-9: +5 USB
PWH-10: GND

ERP-1: ESTOP-IN
ERP-2: GND
ERP-3: RUN-IN
ERP-4: GND
ERP-5: PAUSE-IN
ERP-6: GND
ERP-7: +V-Ext





Size of PCB: 105 x 120 mm

ERP-8: GND
ERP-9: +5 USB
ERP-10: GND

Connect Unused Inputs to GND
X1 : +V-Ext

+V Ext is a voltage that may be applied if e.g. Home sensors or Probe or hand wheel require a separate supply other then +5 Volt from the USB. The +5V Ext is routed to the Home, ERP, PWH and OUT connector.

All signals on the OUT connector are open collector outputs. A separate Voltage may be applied up to 24 Volt.

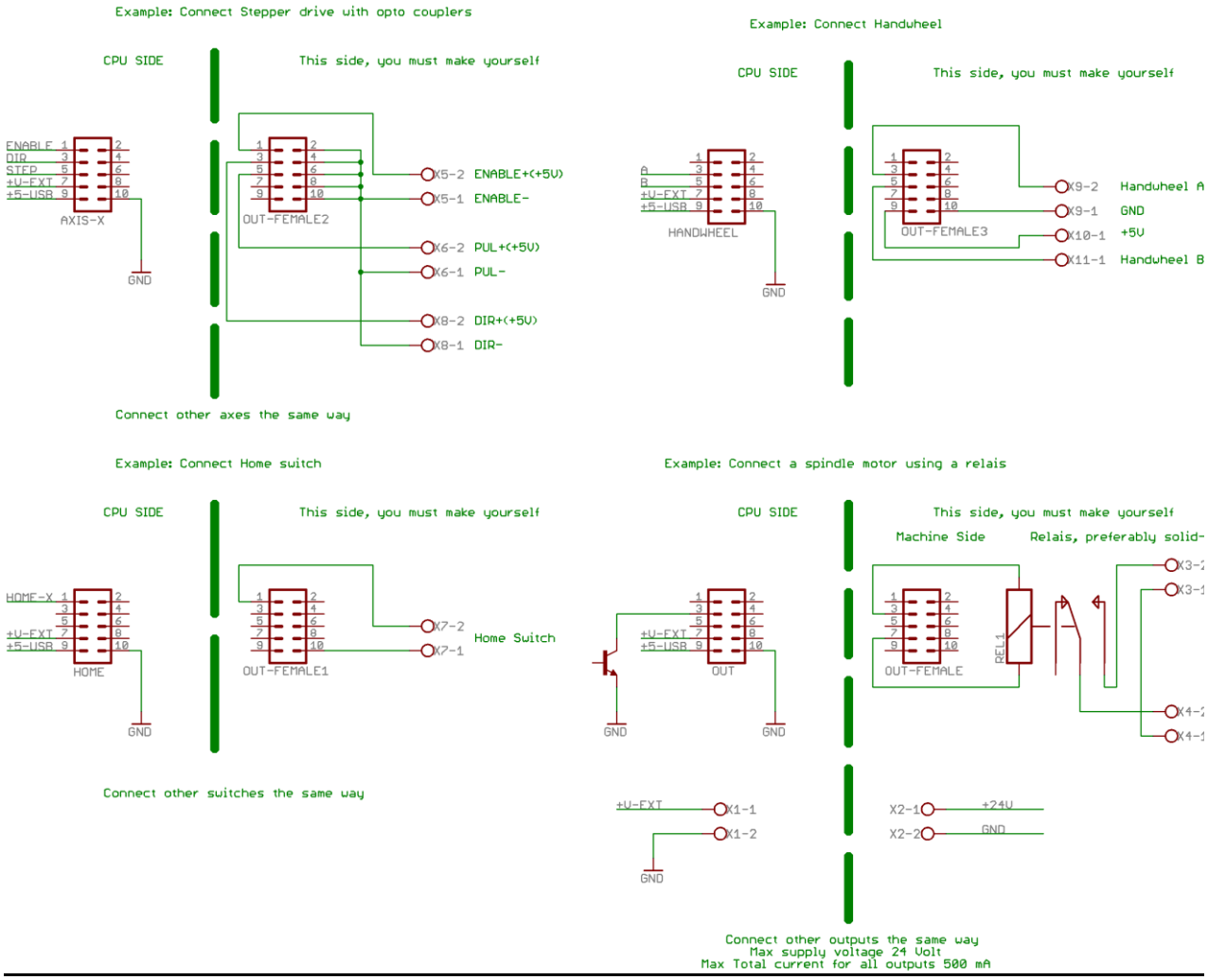
OUT-1: PWM
OUT-2: AUX1
OUT-3: TOOL
OUT-4: TOOL-DIR
OUT-5: MIST COOLANT
OUT-6: FLOOD COOLANT
OUT-7: +V Ext
OUT-8: MACH-ON
OUT-9: +5 USB
OUT-10: GND

The step frequency also determines the pulse width, See table.

The frequency can be setup in the setup screen of usbcnc2.exe

Frequency step pulse (Hz)	Pulse width (µSec)
75085.689	4.96
68259.717	5.62
62571.408	6.29
57758.222	6.96
53632.635	7.62
50057.126	8.29
46928.556	8.95
44168.052	9.62
41714.272	10.29
39518.784	10.95
37542.845	11.62
35755.090	12.28
34129.859	12.95
32645.952	13.62
31285.704	14.28
30034.276	14.95
28879.111	15.61
27809.514	16.28
26816.318	16.95
25891.617	17.61
25028.563	18.28

Connection examples



Output characteristics of USCNC_CPU_4

- Step/Direction/Amp enable outputs are +5 Volt logic.
- Step/direction/Enable outputs can source or sink 50 mA.
- Total current for Step+Direction+Amp enable may not exceed 50 mA
- Max step frequency is 75 KHz, pulse width 5 us.

- All outputs on OUT are open collector and can individually sink 500 mA.
- External voltage must be applied for OUT outputs
- All outputs on OUT together should deliver no more than 500 mA

- Inputs can be a simple switch that connects to the signal and GND

- The PWM output generates a PWM signal with a frequency of 5 KHz.

1.1.1.2 THE AXES

- A maximum of 5 axes named X, Y, Z, A, B or C. In a standard milling machine, the X, Y and Z axes are linear axes, A, B, C are usually rotational axes.

The current version allows a maximum step-frequency of 25 KHz. Suppose you use a micro step controller with 1/8 micro-step. Then the maximum rotation speed of a 200 step/rev motor would be 25000 / (200 * 8) = 15.625 revolutions per second. This is sufficient in most cases.

I myself use 12 x 3 mm spindles and a 1:1 stepper motor to spindle ratio. So the maximum speed of my machine is 3 * 15.626 = 46.875 mm/sec or almost 3 meter/minute. This is quite enough for the hobby CNC machines, where this product is intended for.

1.1.1.3 OUTPUTS

- A spindle in which the tool is mounted, the spindle can be switched on or off using M3, M4, and M5.
- Flood coolant, one of two coolants that can be switched on or off. These can also be used to control e.g. a vacuum cleaner, see M7, M8, M9.
- Mist coolant, the second one, see M7, M8, and M9.
- PWM ON output, switch, to switch on the heat wire or laser power.
- PWN output, 5 KHz, 0-100% adjustable, for controlling e.g. foam cutting wire heat or laser intensity
- AUX1 Output, user output.

The outputs are capable of driving about 24 milliamps normally. This is sufficient to drive a solid-state relay that switches on the mains-supply for spindle etc.

1.1.1.4 INPUTS

- End of stroke input, USBCNC has one shared input that is used for homing the axes. While homing USBCNC first moves in the direction of the switch, when the switch activates the input USBCNC starts moving in the opposite direction until the switch is released. The position captured on the moment of release is set to the position given in the settings window,
  From USBCNC_CPU_3 each axis has its own End of Stroke input for homing.
- Probe input, similar to homing, this input is used to measure the work piece or machine itself using a probe, see G38.2 and the example.
- External error input, some stepper motor/servo drives have an error output that is signaled when an error occurs, the external error input may be used to connect this. USBCNC will stop when the external error input activates.
  This input is no longer on CPU_3 since nobody uses it and external errors can easily be ored to the emergency stop input.
- Emergency stop input, this signal stops USBCNC motion and switches coolants and spindle off. I must remind you that a good emergency stop design usually doesn't rely on software and brings the system in a safe state by shutting down the IO and servo power hardware wise.
- Run/Pause input, may be used for extra buttons on the machine that have the same function as the run/pause button in the GUI.

The inputs can be directly connected to switches without additional power supplies on USBCNC_CPU_2. See also the schematic, which available in at the download area.

1.1.2 Numerical Control Programming Language RS274

RS274 is a programming language for numerically controlled (NC) machine tools, which has been used for many years. The most recent standard version of RS274 is RS274-D, which was completed in 1979. It is described in the document "EIA Standard EIA-274-D" by the Electronic Industries Association [EIA] (see page 4-1). Most

NC machine tools can be run using programs written in RS274. Implementations of the language differ from machine to machine, however, and a program that runs on one machine probably will not run on one from a different maker.

1.1.2 The RS274/NGC Language

The NGC architecture has many independent parts, one of which is a specification for the RS274/NGC language, a numerical control code language for machining and turning centers. The specification was originally given in an August 24, 1992 report "RS274/NGC for the LOW END CONTROLLER -First Draft" [Allen-Bradley] (see page 4-1) prepared by the Allen-Bradley company. A second draft of that document was released in August 1994 by the National Center for Manufacturing Sciences under the name "The Next Generation Controller Part Programming Functional Specification (RS-274/NGC)" [NCMS] (see page 4-1). All references in this user manual are to the second draft. The RS274/NGC language has many capabilities beyond those of RS274-D.

1.2 DEFINITIONS, ACRONYMS AND ABBREVIATIONS

INTERPRETER	A software function that is able to read a text file and execute the commands contained therein.
JOBFILE	A *job* is the text file that will be executed by the interpreter.
GUI	Graphical User Interface.

1.3 MINIMUM PC REQUIREMENTS

- 1.4 GHz Pentium
- 1024 MB RAM.
- Windows XP or Windows 7, Vista does not work on some PC's.
- Screen resolution 1024 x 768
- USB-2 connection

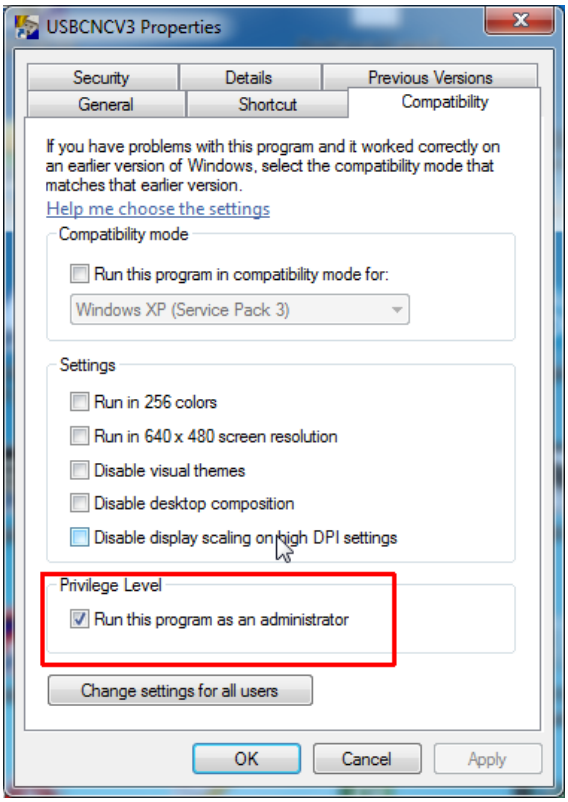
Windows XP and Windows 7 is proven to work fine with USBCNC.
Windows Vista is not recommended for USBCNC, but you can try, it works on 60% of the PC's.

USBCNC requires soft-real-time behavior of your PC. Sometimes a bad driver of your video-card, sound etc may be the cause of problems with USBCNC.
Also some BLUETOOTH drives may cause problems if installed on COM ports. This can be solved by uninstalling the BLOOTOOTH COM ports.

1.4 INSTALLATION OF USBCNC

Download the installation executable from the website download page. Click on it to install the software. Follow the screens.

USBCNC must be started as Administrator. This can be done by right clicking the mouse on the USBCNC Icon and then select run as Administrator.
To avoid having to do this every time, you can change the properties of the ICON by right clicking on the ICON and set the check "Run this program as Administrator".


USBCNCV3 Properties
Security
Details
Previous Versions
General
Shortcut
Compatibility
If you have problems with this program and it worked correctly on an earlier version of Windows, select the compatibility mode that matches that earlier version.
Help me choose the settings
Compatibility mode
Run this program in compatibility mode for:
Windows XP (Service Pack 3)
Settings
Run in 256 colors
Run in 640 x 480 screen resolution
Disable visual themes
Disable desktop composition
Disable display scaling on high DPI settings
Privilege Level
Run this program as an administrator
Change settings for all users
OK
Cancel
Apply

You can start USBCNC now by clicking the shortcut. USBCNC will show in the log window that the connection to CPU failed and that is running in simulation mode, this is OK. You can play

around now in simulation mode and setup the system the real system when you have the hardware.

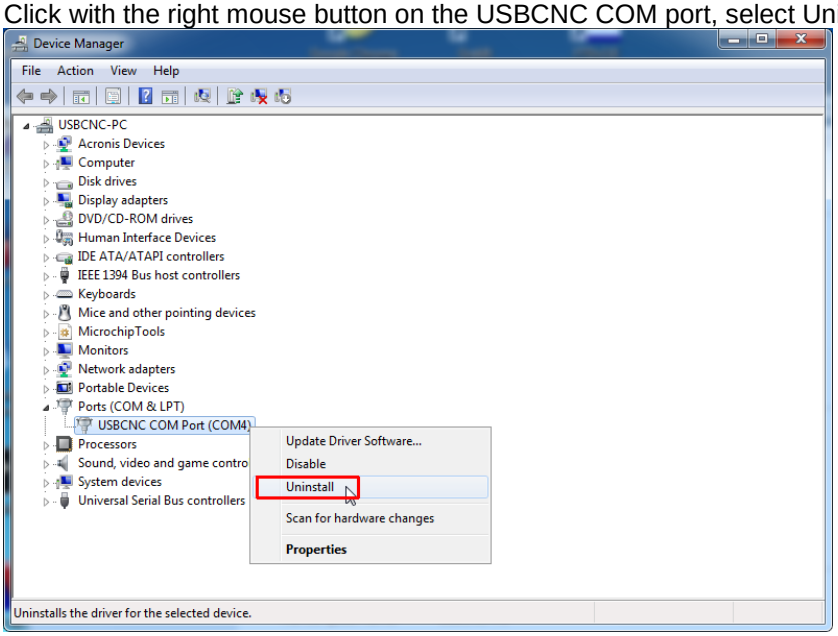
1.4.1 Setup USBCNC driver

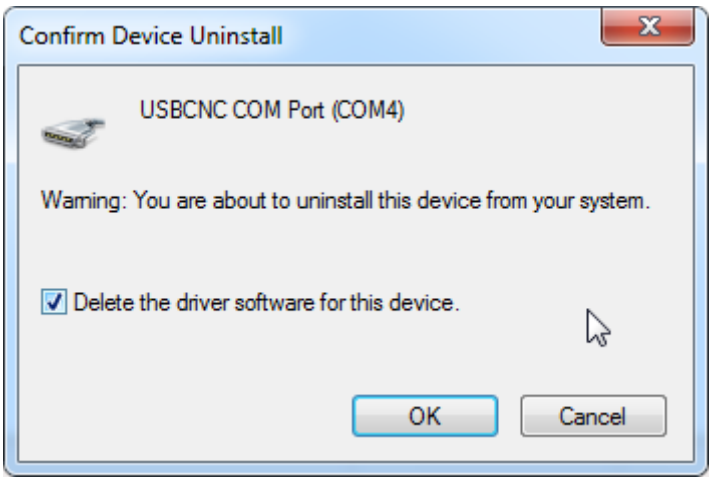
If you have no hardware, you can skip this section and use USBCNC in simulation mode.

On 64 bit windows 7 or Vista, before startup of windows use F8.
In the menu, select the option which disables driver signature verification.
(We are working on this issue)

1.4.2 Remove old driver

If you have a USBCNC version installed before V3.43, you should first de-install the driver, otherwise continue to “Install driver”.
Uninstalling can be done in device manager, so go to device manager, then select ports.
The CPU USB cable must be plugged in.
Click with the right mouse button on the USBCNC COM port, select Uninstall:

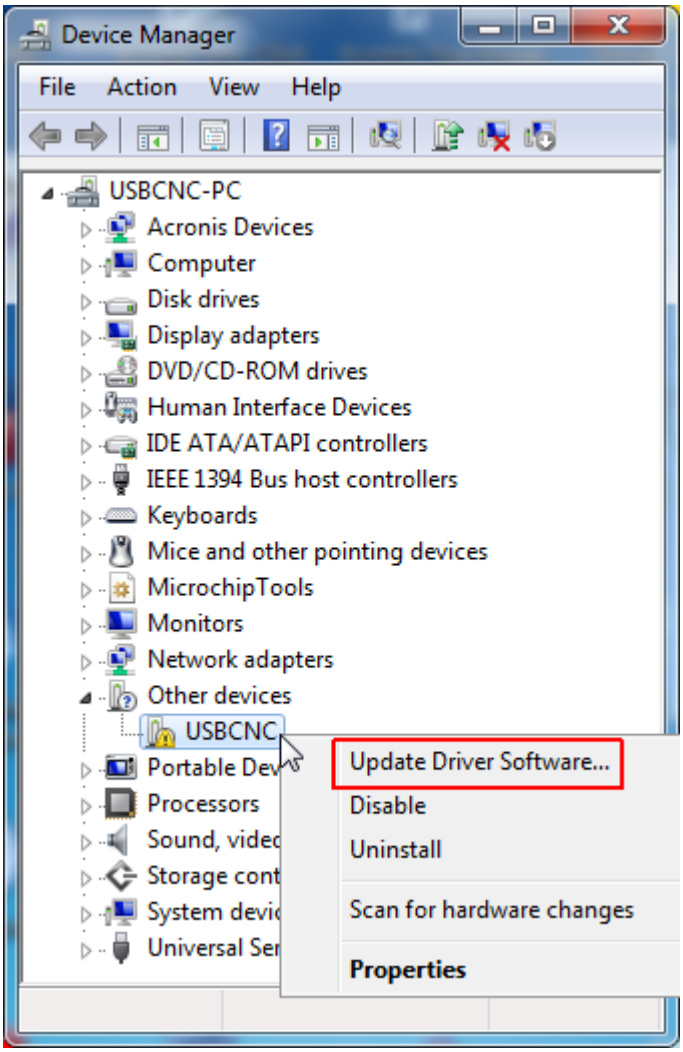



Confirm Device Uninstall
USBCNC COM Port (COM4)
Warning: You are about to uninstall this device from your system.
Delete the driver software for this device.
OK
Cancel

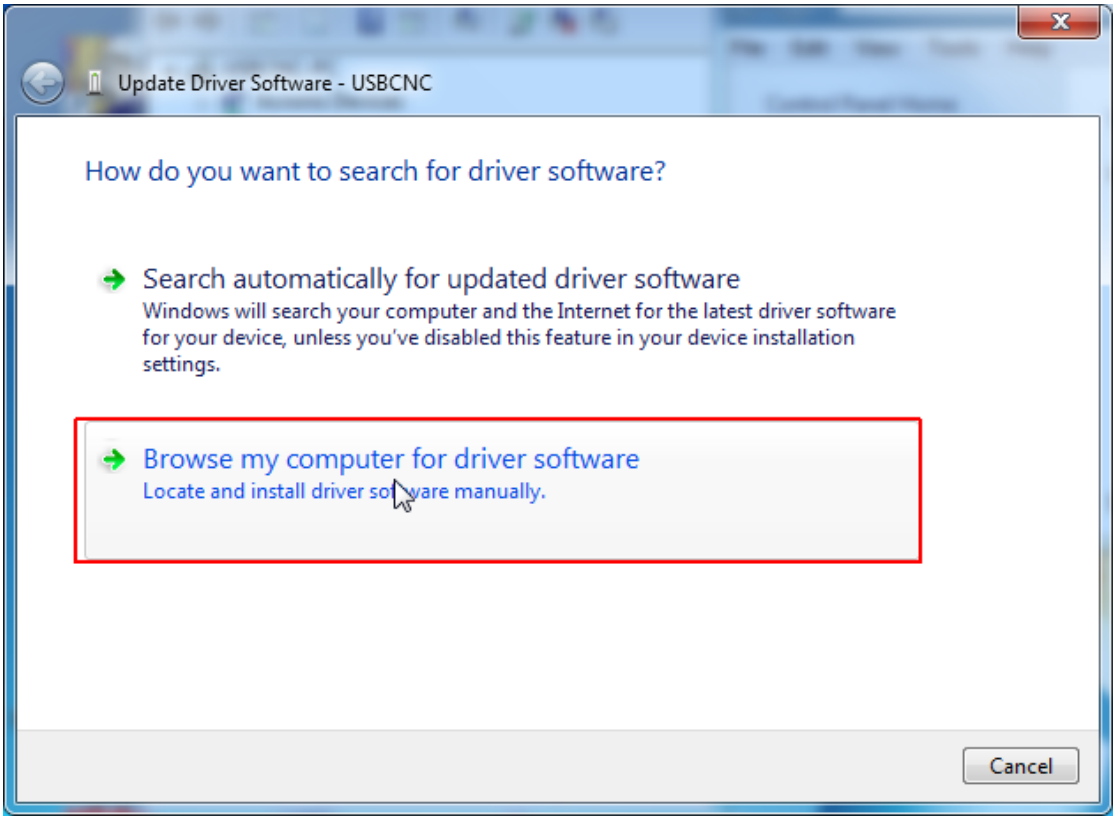
Now reboot the PC.

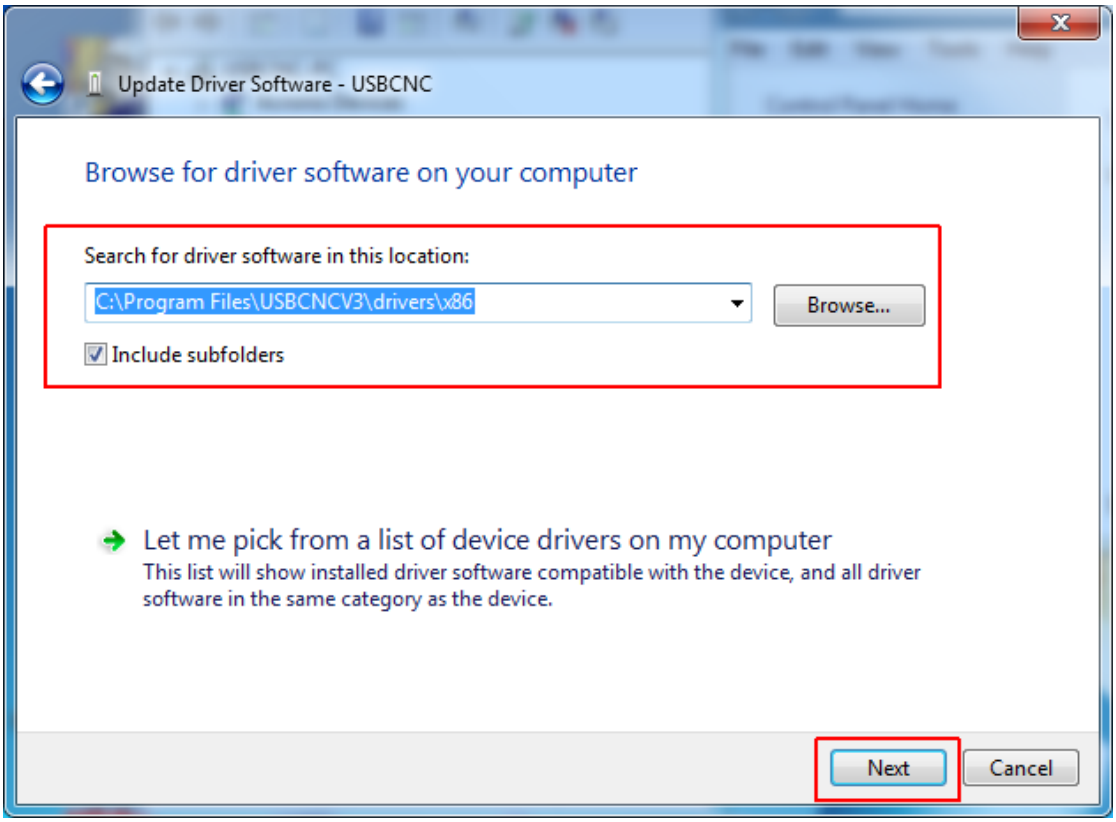
1.4.3 Install driver

When you connect the CPU device for the first time to your system windows will pop up with new device detected, USBCNC.
Windows will probably fail installing the driver.
Go to device manager and select the USB device with a yellow exclamation (“!”) sign.

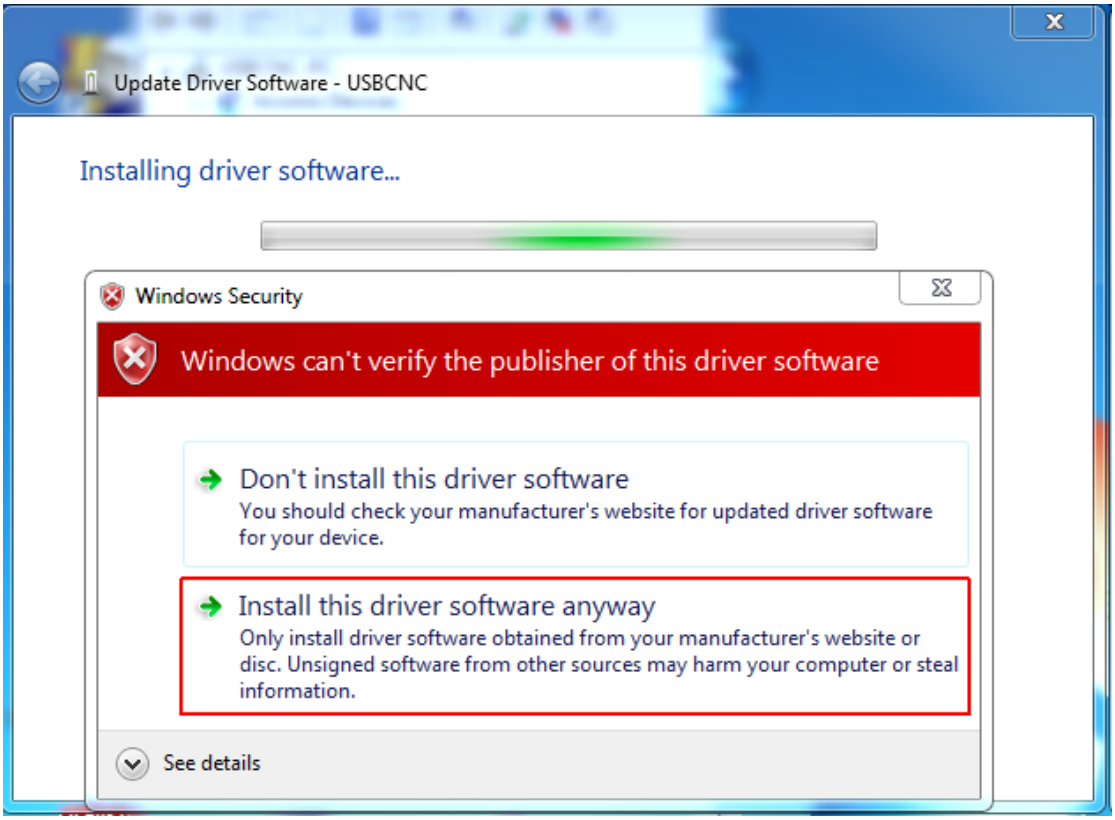


Select update driver software, then select “Browse my computer”:

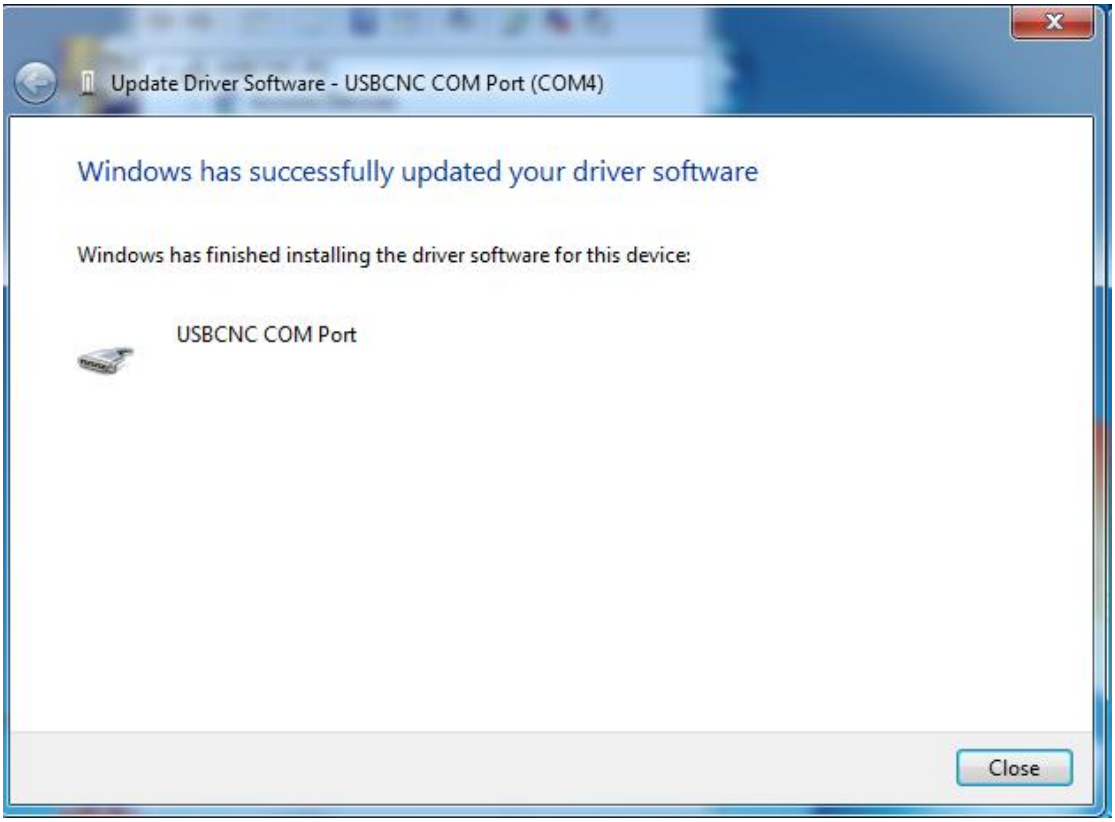

Update Driver Software - USBCNC
How do you want to search for driver software?
Search automatically for updated driver software
Windows will search your computer and the Internet for the latest driver software for your device, unless you've disabled this feature in your device installation settings.
Browse my computer for driver software
Locate and install driver software manually.
Cancel


Update Driver Software - USBCNC
Browse for driver software on your computer
Search for driver software in this location:
C:\Program Files\USBCNCV3\drivers\x86
Browse...
Include subfolders
Let me pick from a list of device drivers on my computer
This list will show installed driver software compatible with the device, and all driver software in the same category as the device.
Next
Cancel

Browse to c:\program files\USBCNCV3\drivers\x86, select next. A new COM port will be installed. Press install anyway if windows says that the driver is not signed by Microsoft.
On 64 Bit windows use c:\Program Files (x86)\USBCNCV3\x64 instead.


Update Driver Software - USBCNC
Installing driver software...
Windows Security
Windows can't verify the publisher of this driver software
Don't install this driver software
You should check your manufacturer's website for updated driver software for your device.
Install this driver software anyway
Only install driver software obtained from your manufacturer's website or disc. Unsigned software from other sources may harm your computer or steal information.
See details

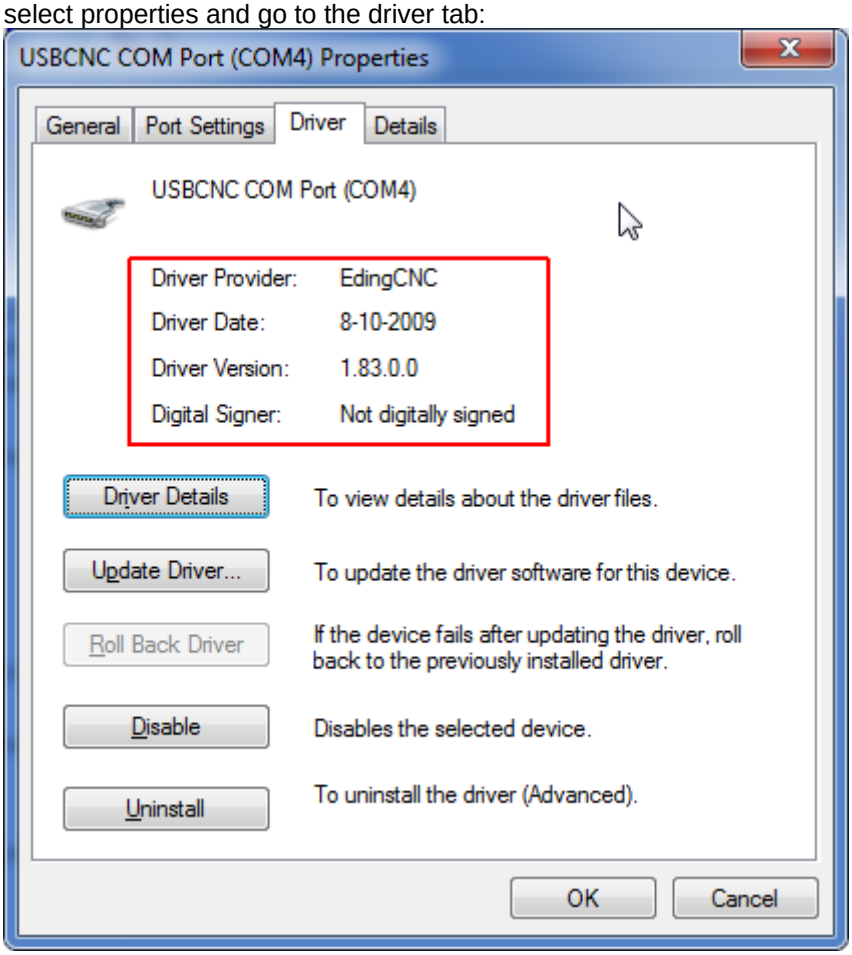
Choose “Install this driver anyway”


Update Driver Software - USBCNC COM Port (COM4)
Windows has successfully updated your driver software
Windows has finished installing the driver software for this device:
USBCNC COM Port
Close

After the installation, disconnect the CPU and shutdown the computer, then reboot the computer.

Connect the CPU.

Verify correct driver installation, go to device manager, right click on USBCNC COM Port, select properties and go to the driver tab:



If this is correct, start USBCNC, on Windows 7, right click mouse, select run as administrator.

Select the COMx port in the setup-USB Connection.

Press Save Changes and close the application (Alt F4 or use the close X at the right upper corner of the window).

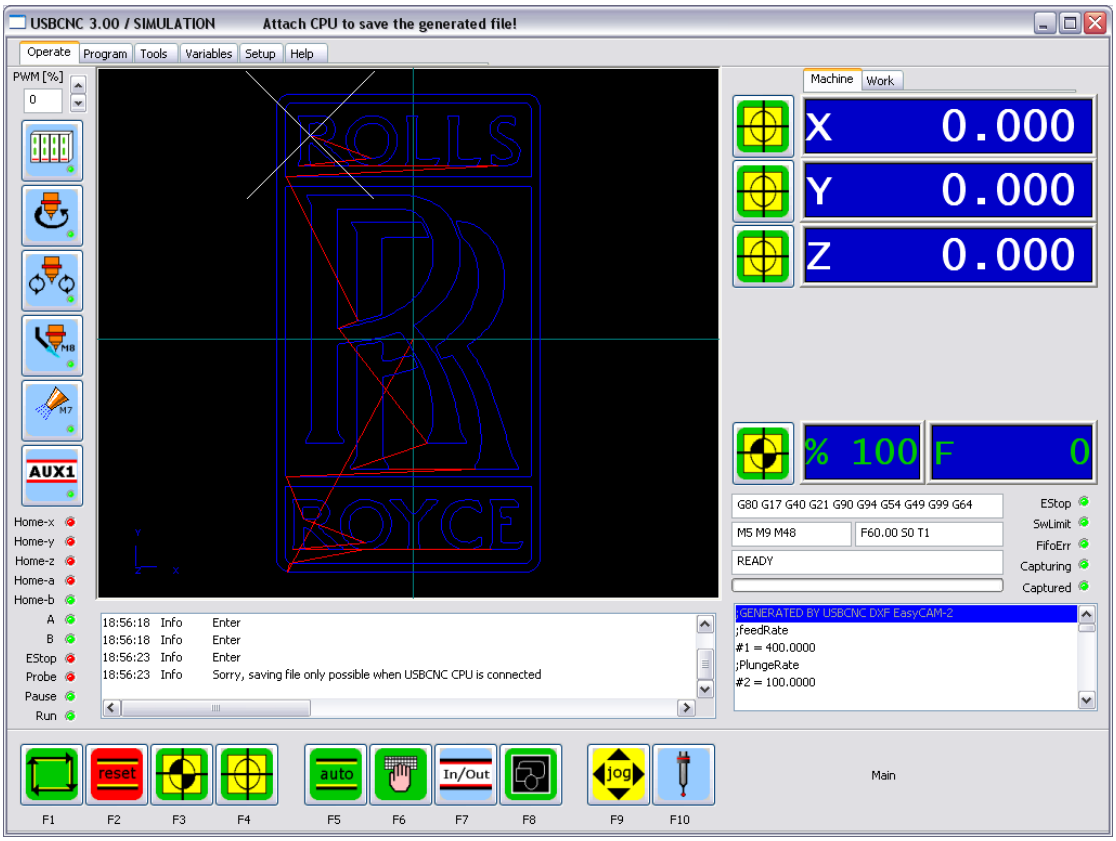
Now restart USBCNC, you should see " USBCNC-5D X.XX" in the logging window at the bottom. This means that you have a connection with the CPU board.

If you fail installing the driver, contact me.

2 The user interface

There are several views:
Operate , Program, Tools, Variables, Setup and Help.
Using control-tab, you can tab through them.

Operate



From this screen all machine operation like jogging running etc can be executed.
The Operate screen is designed such that it is mouse and touch-screen friendly.
All operation can be done without having to use the mouse. Under the function keys are all the functions you need. There is a 2 level menu structure, see the help for explanation.

The amplifiers are switched on when pressing the reset button.
Example to load a G-Code file, press F5 to get into the AUTO sub menu, then press F3 to load the file.

The file is parsed by the G-Code interpreter and visualized in the 3D graphics window. You can PAN, ZOOM, Rotate etc from the Graphics submenu under F8.

Jogging is possible using the Arrow keys:
Arrow keys: X, Y
Page Up/Page Down : Z
Home/End : A
Ins/delete : B

Jogging speed is standard 10%.
By holding the shift key you can jog with 100% speed.
By holding the left Ctrl key, you jog with 50% speed.

At the left of the screen, you see all I/O signals with the current status: Red => +5V, Green 0V. Using the buttons the outputs can be toggled.

Below the graphics screen there is the logging window, it provides user messages, warnings and errors, always keep an eye at this window, especially when things go wrong.

At the right side, you see the axes positions, when homing you use the machine coordinates and for all other operations the work coordinates.
The buttons beside the axes positions are for zeroing the work position, on the background a G92 is executed to perform this. The zero buttons can also be found in the zero submenu, especially for people who do not like using the mouse at the machine.

Below the axis positions you see the actual feed Override percentage and the actual feed when the machine is running.

Below that you see info about the G-Codes, M-Codes and Feed/Speed/Tool.
Further you see the overall machine status, “Ready” when at rest, “Running” when executing a G-Code file, etc. When the machine is in error, it says ERROR, or ABORTED when ESC was pressed. The Escape key behaves like emergency stop, when pressed the machine stops immediately and all I/O’s are switched off. Since the stop is immediately without ramping down the speed, the position of the motors will be lost and you need to HOME the machine again. So use the escape key only in emergency situations.

The progress indicator and the LED’s below the machine status are the status of the USBCNC CPU. The progress indicator shows the fullness of the buffered motion and the LEDS show other status:

E-Stop: Turns red when the external E-Stop is activated

SWLimit: Turns red when during execution of a G-Code file the SW limits where crossed, in this case a smooth stop is executed without losing the position, so when that happens, just reset and continue without homing.

FifoErr: The motion send to the CPU is buffered into a Fifo at the CPU side, while running this buffer may never run empty, when that happens anyway, there is a problem with the speed of the USB communication, the machine will stop immediately. This will normally never occur when you machine is setup correctly.

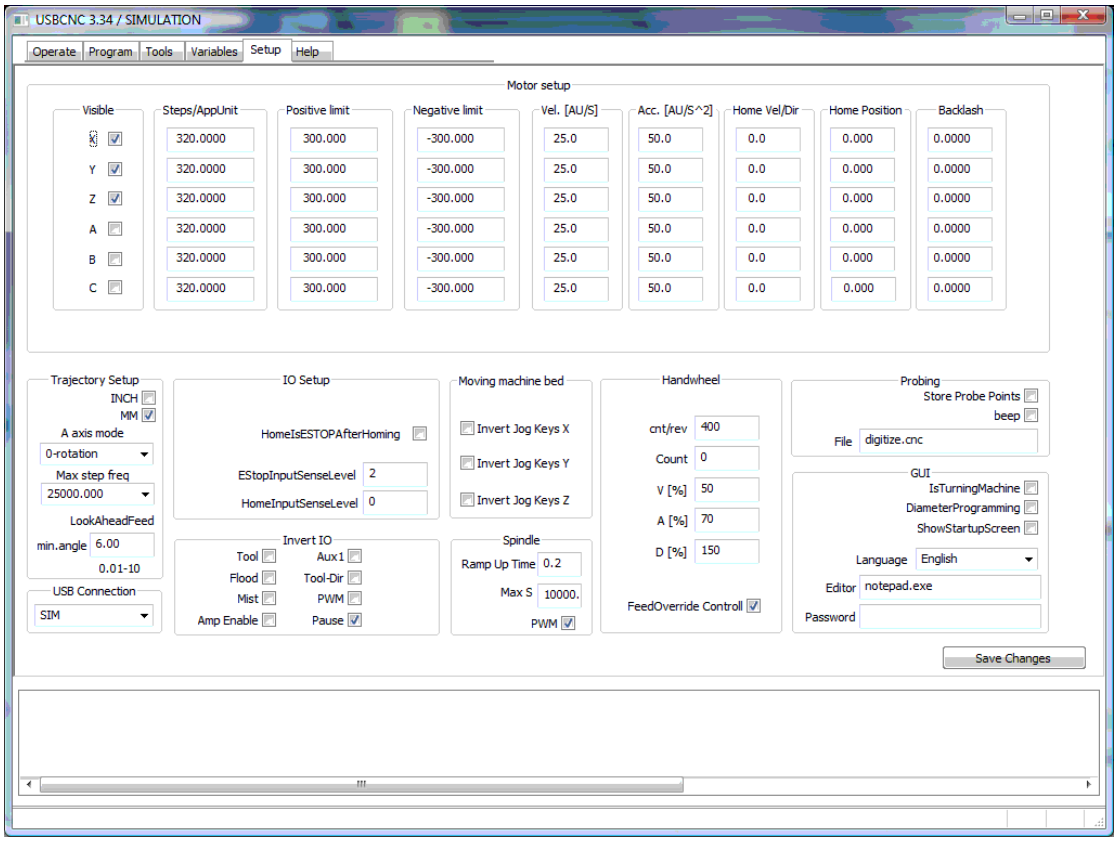
Capturing: When homing or probing the internal position latch in the CPU is armed to latch the position when the home switch or probe triggers. Capturing means the CPU is Armed to do this.

Captured: Becomes active when the latch has captured the axes positions, this happens very accurate at every stepper pulse.

All functions of the Operate screen and a list of G-Codes can be found in the Help screen, look at the help TAB when running the program.

2.1 CONFIGURING THE SYSTEM

Before the system is actually used we have to setup the system to accommodate the machine, we do that in the setup page:



2.1.1 Language setup

Language setup: Speaks for itself.

2.1.2 USB port

Language setup: See chapter 1.3 about installation.

2.1.3 Motor setup

Steps/AppUnit : Fill in number of steps per millimeter for millimeter mode or number of steps per inch for inch mode.
Fill in a negative number to reverse the motor direction.

Positive limit: Maximum machine position.
Negative limit: Minimum machine position;

Vel : Maximum axis velocity
Acc: Maximum acceleration
Visible: Check to enable this axis, any combination is allowed, some configurations have special meaning:
XYZ: Standard milling machine
XYZA: Milling machine with 4th axis or foam cutting machine

XYZAB, XYZAC, XYZBC: five axis milling machine.
XZ or XZC or XYZC: Lathe, this is in preparation. For lathe the axes are connected in order of visibility, so if you have a X/Z configuration, the X axis is connected to the first axis on the board and the Z axis is connected to the 2nd .

2.1.4 Homing setup

Home Vel/Dir: Homing velocity, sign determines homing direction.

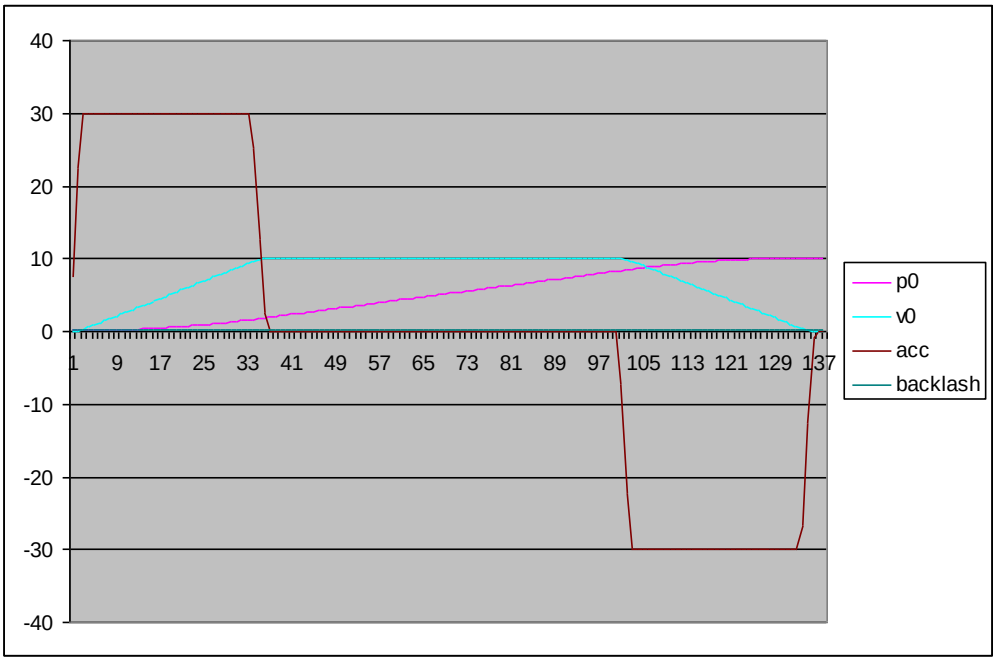
When the velocity is set to 0, the axis is homed manually, see the homing and coordinate systems chapter 2.5.

Home Position: Machine position at the moment the home switch activated. This determines the machine coordinates. It is not really relevant where the machine zero point lies, it should only match with the MIN/MAX position.

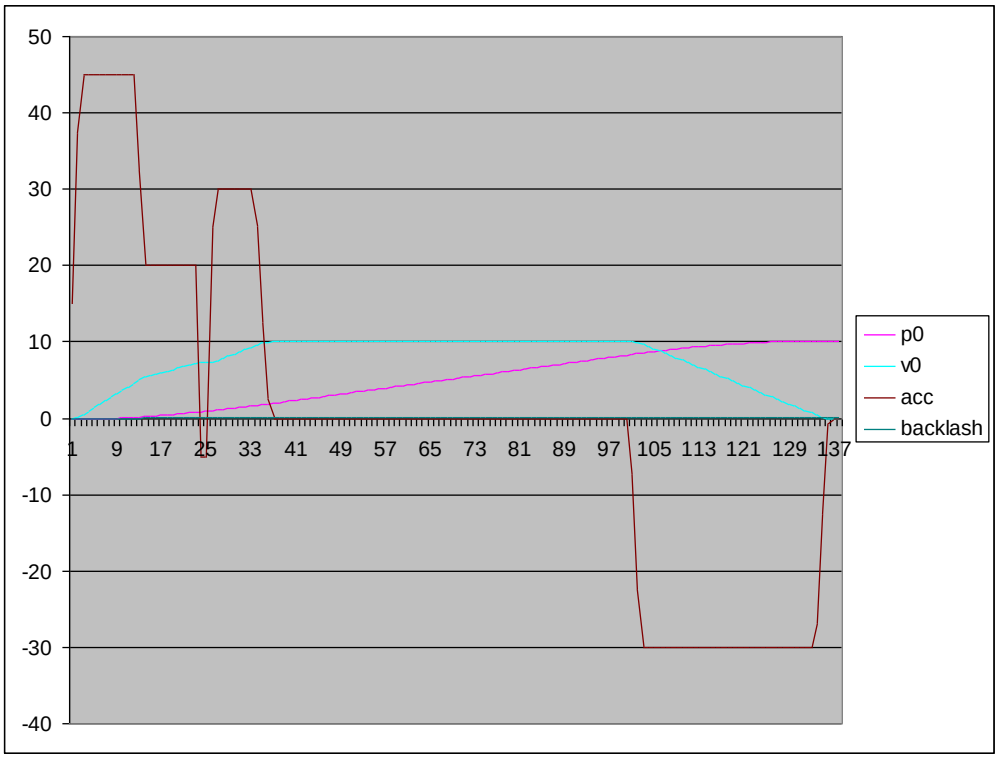
2.1.5 Backlash setup

Set the amount of backlash for each axis that the software should compensate. Experiment with velocities and acceleration, the backlash compensation demands more from your motors than without backlash compensation. Do not try to compensate more than 0.25 millimeters. If there is more backlash, try to reduce it mechanically first. The backlash compensation superimposes a second movement (the backlash) on top of the normal movement when the direction reverses. You can see the impact on the motion profile in the figures below. Here you can see the extra demands on the motors. Especially look at the extra acceleration that is caused by the backlash compensation. A non micro step drive in combination with a relative good motor may not be able to follow the profile.

A movement from 0 to 10 mm without direction reversal. It is a beautiful 3rd order profile as you can see. The numbers on the X axis are 10 ms units, total move is about 1.37s.



The next figure shows the same movement with direction reversal. The compensation value is 0.25 mm for this measurement, this is a relative large value.



2.1.6 Trajectory moves setup

For A-Axis 3 options:

0: Standard rotation axis, which slaves to linear axes.
Feed is F.

1: Linear axis, mainly for foam cutters.
Feed calculated from X/Y or A/Z, whichever moves the largest distance.

3: 4th axis milling.
Feed calculated such that is matches the tool-material surface on the cylinder that is milled.

INCH: Machine setup is in inch mode.

MM: Machine setup is in mm mode.

MAXFREQ: The maximum step frequency that the CPU will generate. For CPU-4 it is sometimes required to lower the maximum frequency, because the drive is unable to handle the 75000 steps/sec. For instance, when you build the PICSTEP driver and want to use it with CPU 4, set the max frequency to 50 KHz, because the PICSTEP driver cannot handle frequencies above 50 KHz.

LAF: Enable Look Ahead Feed calculations, motion segments that are connected with a smaller angle as specified in min.angle will accelerate through which will give higher speeds especially with programs consisting of small motion segments. This is a unique feature which you don't find easily on low cost CNC controllers.
Be carefully with the min.angle setting because this cause acceleration spikes, it depends on your machine and the speed up till what extend this is possible. I suggest performing tests with en check whether you get step pulse loss.
A value of 0.1 is generally safe. Segments that are really tangential connected

will move fast that way.
An example of what I use:
When drawn a circle using CorelDraw of 100 mm in diameter, and exported as HPGL CorelDraw generates small line segments of approximately 6 degrees. Now I have set the min.angle to 6, this gives the possibility to mill the circle with a speed of F6000 while without LAF the speed would be approx F1300 on my machine.

2.1.7 IO setup

For all switches:

0 : Active low
1: Active high
2: Switch off this function, if you don't use it.

HomeIsESTOPAfterHoming:	use this if you want to use the end of stroke switches as emergency stop. When the machine reaches the end of stroke switches the machine will be stopped immediately and all IO's will be switched off. If you want hardware limit switches on both sides, then use separate limit switches and connected them to the E-Stop input.
EStopInputSenseLevel:	use this if you have an external emergency button connected.
HomeInputSenseLevel:	set the level of your end of stroke switches, these are used for homing the machine.
spindleRampUpTime:	Time between spindle on (M3/M4) and the first move.
Invert Outputs:	Check if you want to invert the output, e.g. the PICSTEP 4 card amp is enabled when the signal is low.
Invert JogKeys:	Inverts the movement of the keyboard keys, for moving bed machines, the bed moves in the direction you press the arrow.

2.1.8 Spindle and PWM setup

MaxS:	The speed of your PWM controlled spindle when the PWM signal is at 100%.
PWM:	Check this when you want to use the PWM output to control the spindle speed.
Ramp up Time:	The software waits this time between switching on the spindle and starting the further machining.

2.1.9 Hand wheel Setup

This applies only to CPU-4

Cnt/Rev:	The number of counts of the hand wheel for one revolution, usually 400 for most CNC hand wheels.
Count:	Shows the actual Han wheel count value, try to turn the hand wheel and see it change.

V[%]: Percentage of velocity from selected axis, this is the maximum **velocity** the axis will move when using the hand wheel.

A[%]: Percentage of acceleration from selected axis, this is the maximum **acceleration** the axis will move when using the hand wheel. I recommend to use 100% here.

D[%]: Percentage of acceleration from selected axis, this is the maximum **deceleration** the axis will move when using the hand wheel. I recommend to use 200% here. Try playing with it.

FeedOverride When checked, hand wheel is used to control the FeedOverride. The feed override can be controlled from 0% (Stop) to 300%. The maximum velocity and acceleration specified for the motors will not be violated.

2.1.10 Probing Setup

StoreProbePoints: The touch points are stored in a file when this is checked. This is used for digitizing.

File: The file name for storing the touch points. The file is opened at the first probe touch en closed when a M30 is encountered, usually at the end of the G-Code program.

2.1.11 GUI Setup

IsTurningMachine: Check if you machine is a turning machine, this effects mainly the 3D display which shows the X-Z plane for turning. Also the jog keys operate differently.

DiameterProgramming: Check if you want diameter programming for turning, all X-axis values are interpreted as diameter. The effect is that all movements in the X-axis are divided by 2.

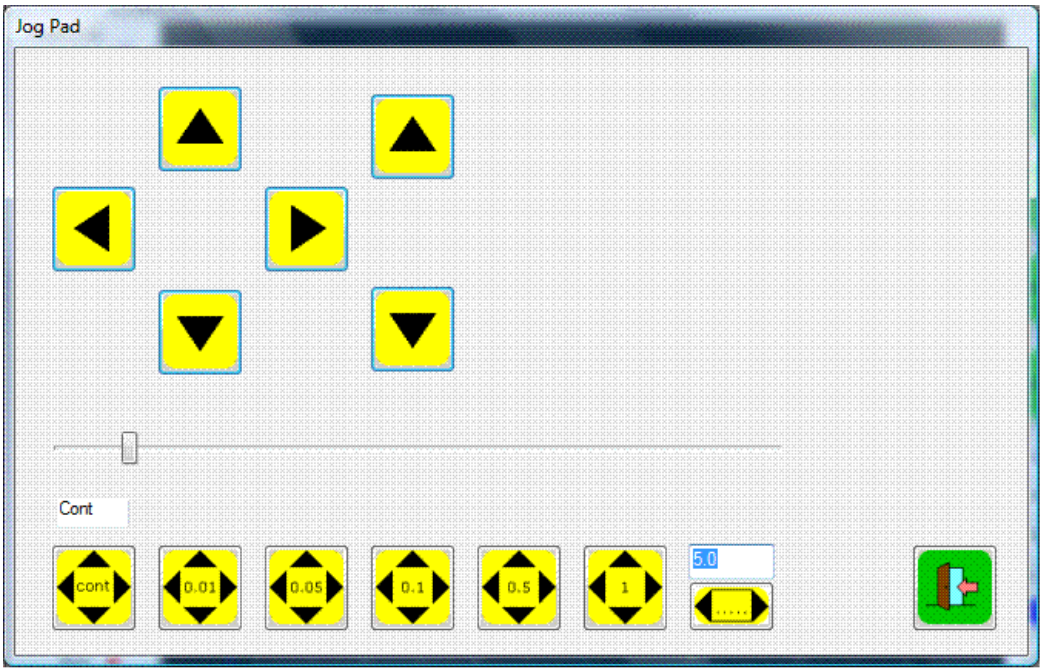
ShowStartupScreen: When checked, the startup screen is shown when USBCNC starts.

Language: Select your preferred language here.

Editor: Specify your favorite editor here. I recommend notepad++, it is freely downloadable at internet. E.g. for notepad++, specify c:\program files\notepad++\notepad++.exe.
The advantage of notepad++ is that the editor jumps to the actual G-Code line immediately, very handy when programming G-Code.

Password: You can protect the setup parameters from being modified by unauthorized persons by using a password. Leave empty if no password is desired.

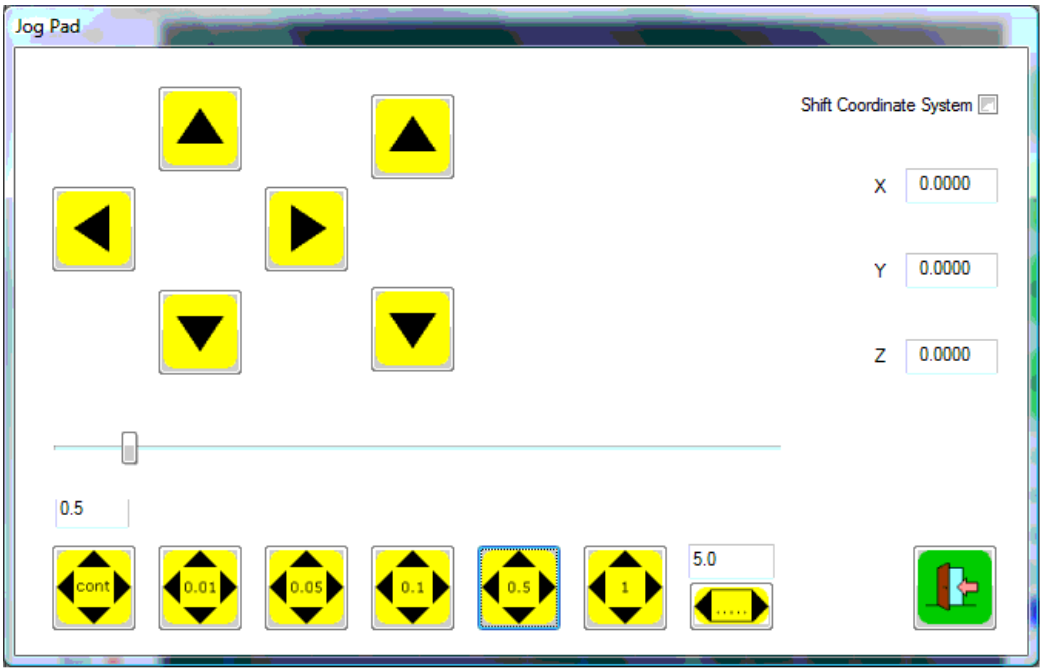
2.2 THE JOGPAD



With the jog pad you can jog the axes.

- continuous mode the axis moves as long as the button is pressed and stops when the button is released.
- Step mode 0.01 to 1 allows to step the axes. Each button press moves the axis one step.
- User step mode is the same as step mode but allows the specify the step-size.

When step mode is chosen, shift coordinates becomes visible:



When selected, jog-step functions as normal, the axes move one step at a time. The work position however remains the same. This is accomplished by modifying the active G92 offset. It is useful when e.g. during engraving you want to run the G-Code program again, but a little deeper in Z. E.g. you want

to run the program 0.1 mm deeper, select jogstep 0.1 and check “shift coordinate system” . Now press de arrow down button to move Z 0.1 mm down. Notice that the axis moves down but that the position remains the same. When you run your engraving program again the engraving will be 0.1 mm deeper into the material.

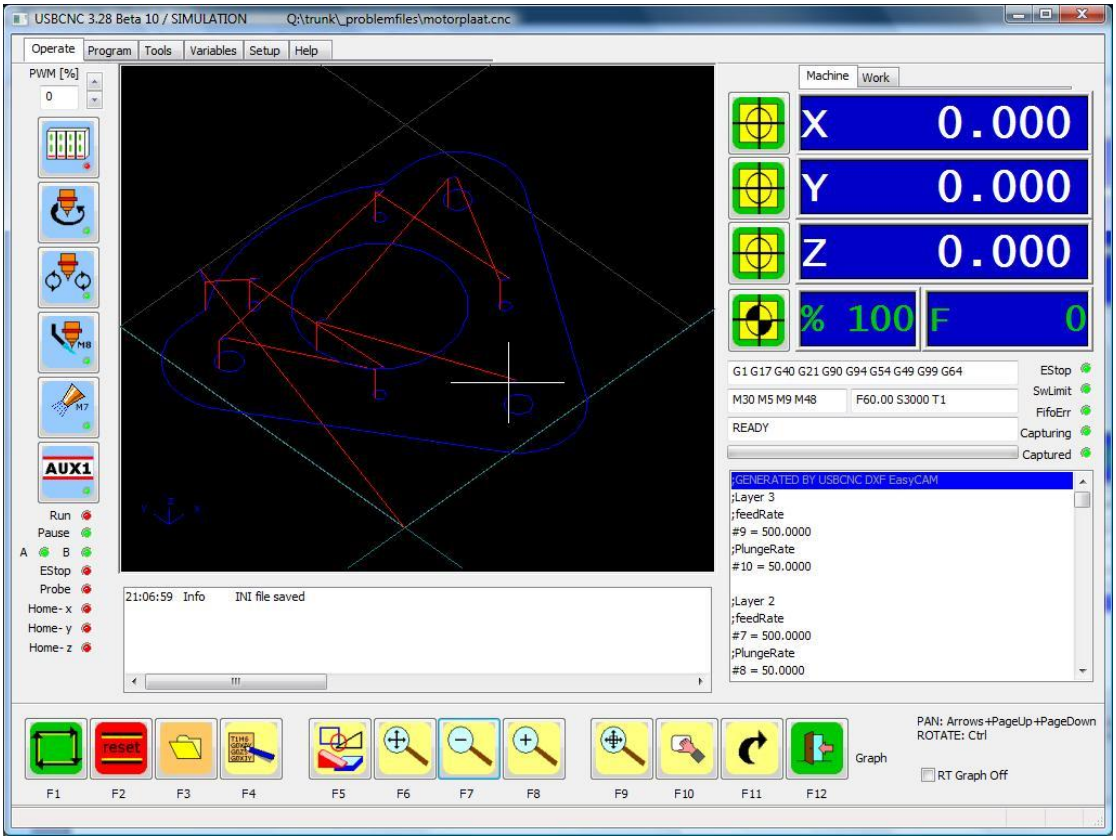
This option is also very handy during turning. Your program has run and you measure the work piece and see its diameter is still a bit too big. So now use the –X button to compensate the diameter. Run the program again and your work-piece diameter will be correct.

The amount of shift is shown at the right side. To reset the value to 0, which has no influence on the active offset nor machine position, uncheck, then check “shift coordinate system”.

2.3 THE GRAPH VIEW

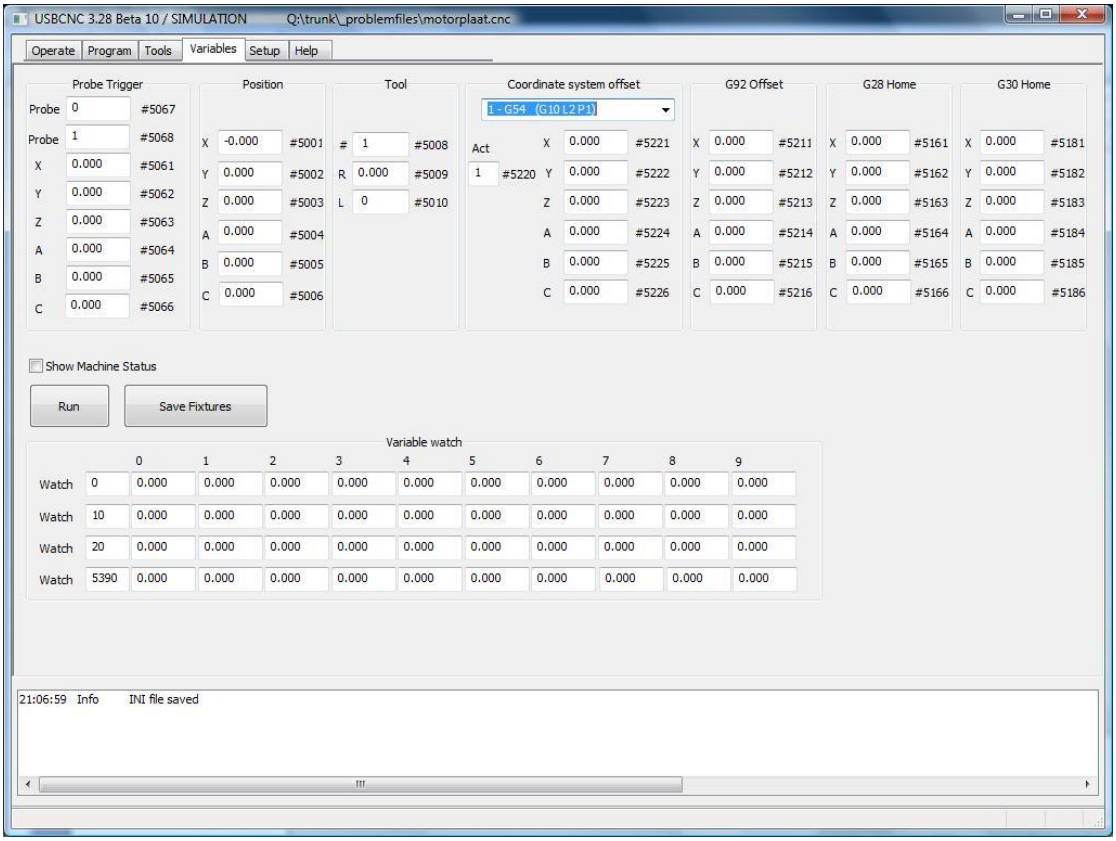
The new graph view shows a grid of 50mm in mm mode or 2 Inch in inch mode projected on the machine bed (X-Y surface). For a representative view it is important that the axes limits are correctly filled in and that the machine is homed manually or automatic. The current work coordinate system origin is shown as a cyan colored cross in the x-y plane. When you press the preview update button, a preview is shown of the loaded G-Code program. The preview is created by running the entire g-code file through the interpreter. So when interpreter errors occur, this is shown in the log window and in the operate view the program list box shows the wrong line in red color. Note that there can be inaccuracy in what the display shows, this is there because of performance and memory usage limitation reasons.

Zooming, rotate, 2D/3D view and other possibilities are found in the graph sub-menu, see the wheel pocketing example below.

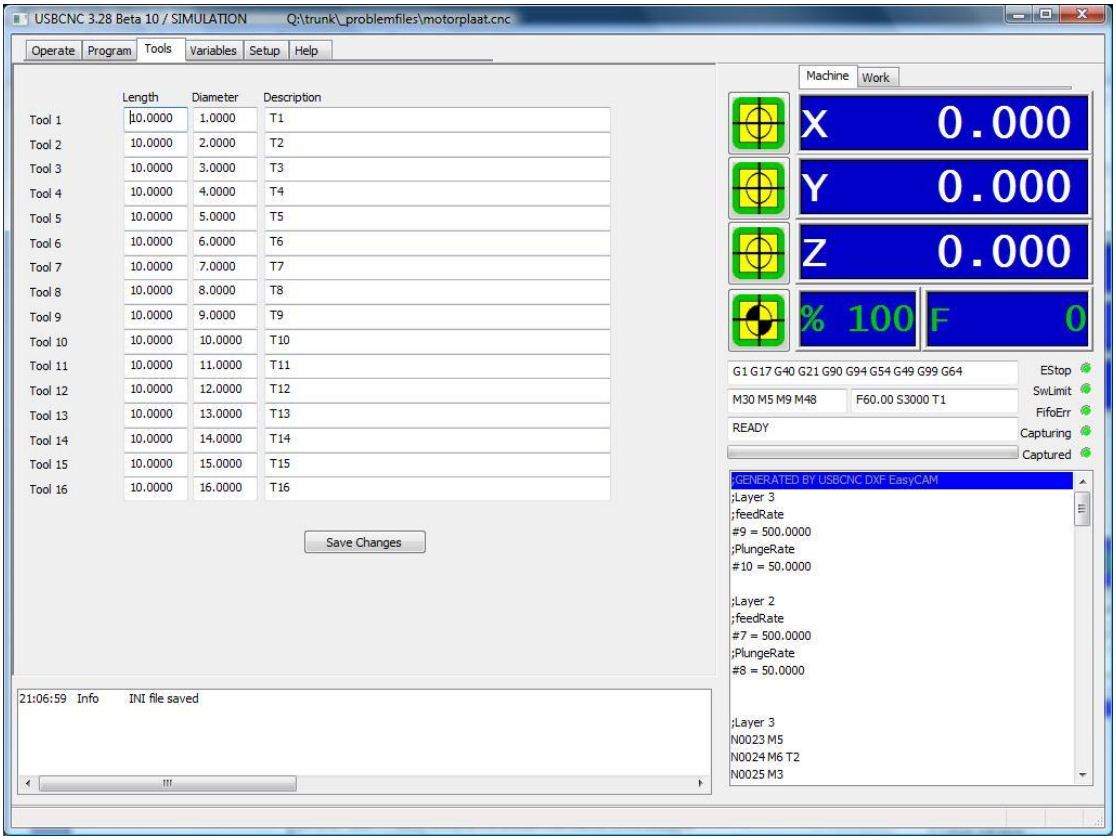


2.4 THE VARIABLE VIEW

This window shows the standard variables used by the G-Code interpreter.
It also contains 4 watches to show your own variables if you are going to use the extended programming features. You will understand the meaning of this window after reading the G-Code interpreter functions and extended programming with variables.



2.5 THE TOOLS VIEW



In this view you can define 16 tools with a length diameter and description.
For Lathe operation there is additional and X-Offset and tool Orientation parameter.
The tool information is used when you use the tool radius and or tool length compensation functions of the G-Code interpreter (G40 – G43).

2.5.1 Tool change

A tool change is performed in G-Code by M6 Tx where Tx is the new tool number. Tool number 0 means no tool.
Normally the program is stopped on a tool change, with a user message to change the tool, pressing run again will continue the program. If you don't want the program to stop, check AutoToolChange in the automatic menu bar. This setting is saved when you press save ini file in the setup screen.

2.5.2 Automatic user defined Tool change

When you want to define you own tool change cycle, you can edit the file "macro.cnc" in the USBCNC directory. When an M6 Tx is encountered, this is translated to a GOSUB of subroutine change_tool in the "macro.cnc" file. See M6 description, and example is provided.

2.6 HOMING AND COORDINATE SYSTEMS

As I am like most people and don't want to read a comprehensive manual, but start right away. So I have written this little tutorial, it explains how to home the machine and use the coordinate systems in a simple way. This part is very important to read, you will enjoy operating the machine more if you use the coordinate systems the right way!

When your machine is switched on, all the axes can be at any position, this position is unknown by the software. The software however needs to know the position to show a correct graphic in the graph screen and also for preventing damage to your machine by running further than the machine allows. The process to match the machine position with the software is called homing. Homing can be done either manually or automatic if end of stroke switches are mounted. This tutorial describes manual homing.

2.6.1 Manual homing the machine

Homing is the first thing you always do after switching on the machine, I recommend to make a habit of it. Suppose your machine limits are:

X: +300 mm and -300 mm
Y: +200 mm and -300 mm
Z: +100 mm and 0 (0 is the bottom surface of the bed)

Set the Home velocity to 0 for all axes that have no EOS switch.

Mark a point somewhere on the machine that you want to use as home reference point, let's say X= -200.0mm, which is 100.0mm from the left edge and Y= -150, which is 50.0 mm from the lower edge. For Z we take to bottom of the bed at Z=0 mm.
This position x=-150, Y=-50, Z=0 is entered in the Home Position values in the set up screen, this need to be done once.

Move by using the arrow keys the X,Y axes to the marked position on the bed and move the Z completely up to the surface of the machine. Use the shift key to move fast. When the machine is at the position press the Home button in the Home submenu, F1-F5 for X-B.

Be sure that you have set the home velocities of the axes to zero, otherwise the axes will start to move. Now click the buttons X, Y, Z, and A if you have an A-axis. That is all, the axes are now homed and the software now knows the machine position.
As a side effect, now also the software limit switches are enabled which protect you from jogging further than the machine can go. Also the Software limit guard is on that will stop a running program when going beyond the limits.

You may also have noticed that the position mode is set to "machine", this is because homing directly affects the machine coordinate system. From this point the machine coordinate system, is not changed any more, it stays as is.

HINT: Move your machine always back to the home position if you are done with the machine. You don't have to move manually to this point next time when you switch back on the machine. You can do a fast move in machine coordinates like this: g53 g0 x0 y0 z0, or first undo the preset (preset dialog, undo preset) and then do a regular G0.
Another possibility to move quickly to the home positions is using g28,
In the variable window set G28 home positions to the same value as the home positions in the set up window. Now you have to type only g28 to go to the home position.

2.6.2 Automatic homing the machine

For automatic homing the home velocity needs to be set to another value than zero, use an equal or lower speed than the axis maximum speed. The axis should start to move in the

direction where your homing switch is mounted, when it is needed to reverse the direction add a minus sign to the homing velocity. Also setup the endOfStrokeInputSenseLevel correctly. When the led's are green when the switch is not activated put a 1 here, when the led's are red when the switch is not activated, put a 0. This depends whether you have used normally open or normally closed switch. I recommend normally closed switches here.
Use the homing sub menu to home your axes. The machine first moves until the switch activates, the ramps down and stops. Then the direction reverses and ramps down when the switch releases. At the moment of the release of the switch, the position is captured and used to set your machine position correctly.
The home submenu axis has a button or F11, to home all axes in a sequence automatically.

F11 loads the homeseq.nc file, with this you can home all axes automatically.
A typical homeseq.nc file looks like this:

```
Home Z (Do z first)
Home X (Then X)
Home Y (Then Y)
G53 G0 X0 Y0 (Move x and y to 0 in machine coordinate system)
```

Note that this button is also available below near the axis positions.

2.6.3 Work versus Machine coordinate system and zeroing

The machine coordinate system does not change, however we want to be able to do the milling of our part anywhere we want on the machine. We will normally use the "work" coordinate system, we can shift it anywhere we want. This can be done with several G-Codes, which are explained in chapter 3, it can also be done using the "preset" button on the operator screen, we'll see this in a minute.

Suppose our g-code file containing the work piece is created with an origin of X=0, Y=0, Z=0. This is because you have drawn your part in a CAD program beginning from these coordinates and then converted to G-Code.
Now you have put your raw material somewhere on the machine, probably not at coordinates X=0, Y=0, Z=0.
By the way, I prefer to define the upper surface of the material as Z=0, such that a negative Z value goes into the material.

Just move to the zero point of the work piece and there press the zero buttons in the operate screen besides the position display.

For the advanced users: The zeroing can also be done using a measuring probe connected to the probe input. Probe sequences can be defined by yourself with the files in the USBCNC directory:
ZeroX.nc
ZeroY.nc
Etc
These probe sequence can be chosen using the probe sub menu button.

If you want to do it a more advanced way, look at G55 .. G59.3 and also at the G92 variants.

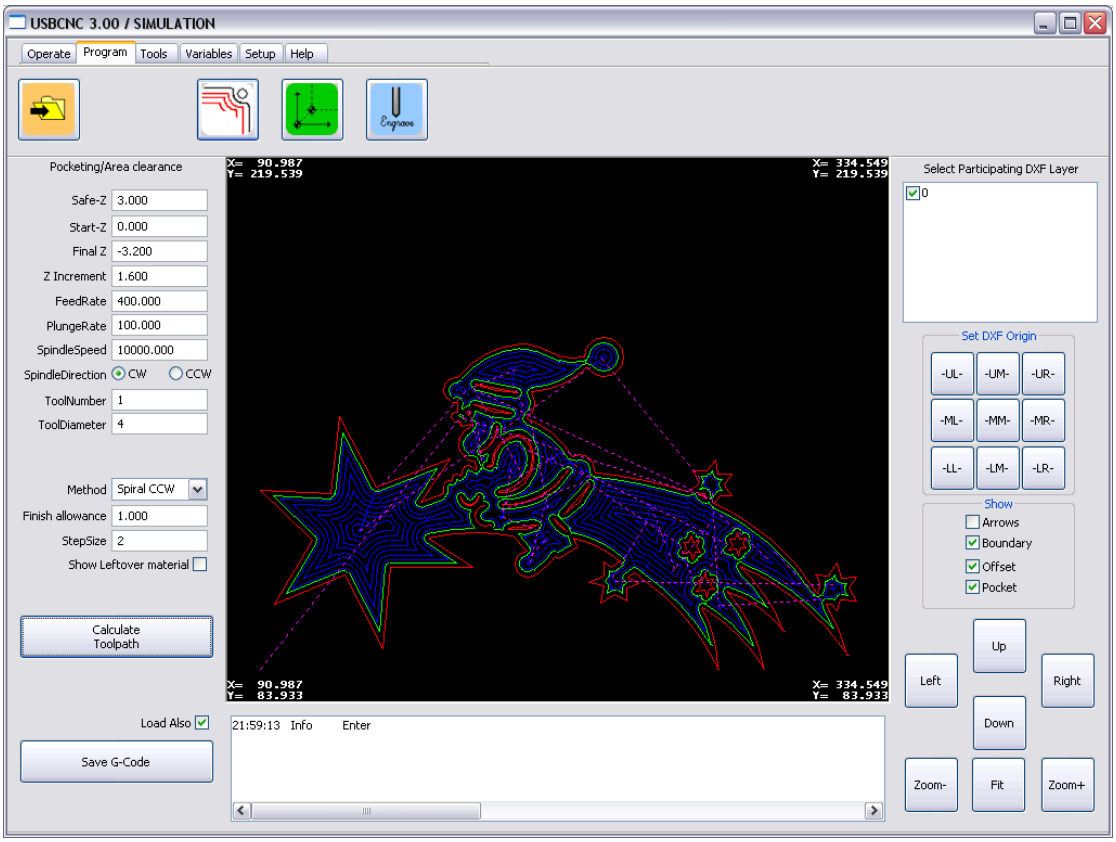
When homing and zeroing is performed, the milling can start:

When the program is loaded, go to the graphics screen (Alt-g) and press update preview, you will now see exactly where the part is going to be milled at the surface of you machine bed.

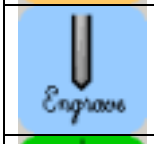
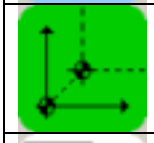
Now press the F4 key or the run button to start milling, go to the graphic screen and switch real time graph on to see what the machine is doing.

That's all for this tutorial, happy milling!

2.7 DXF AND HPGL IMPORT



USBCNC uses a build in CAD/CAM library for these advanced import functions. You can load a file and then perform one of these operations:

	Loads a DXF or HPGL file
	Select engraving, this is milling over the lines from the drawing.
	Select profiling, this is for milling out objects and taking the tool diameter into account.
	This is for pocketing, to mill out the complete object.
	Drilling, draw points in the DXF file to use this.

After loading a DXF file, all layers will be visible. You can unselect layers at the right side, such that you see only the part that you want to use.

You also can change the origin of the drawing by pressing the appropriate button under the layer selection list box. The positions of the buttons give the positions of the origin. So e.g. when you press the upper right button, then the most upper right position of the drawing will become x=0, y=0 when milling.

The DXF import supports:

- Lines
- Arcs
- Circles
- Poly lines with arcs
- Points for drilling

The sequence of using these features is:

1) Load drawing
2) Select the correct layers
3) Apply origin offset if wanted
4) Set correct parameters
5) Calculate tool path
6) Save tool path and optionally immediately load it for milling.

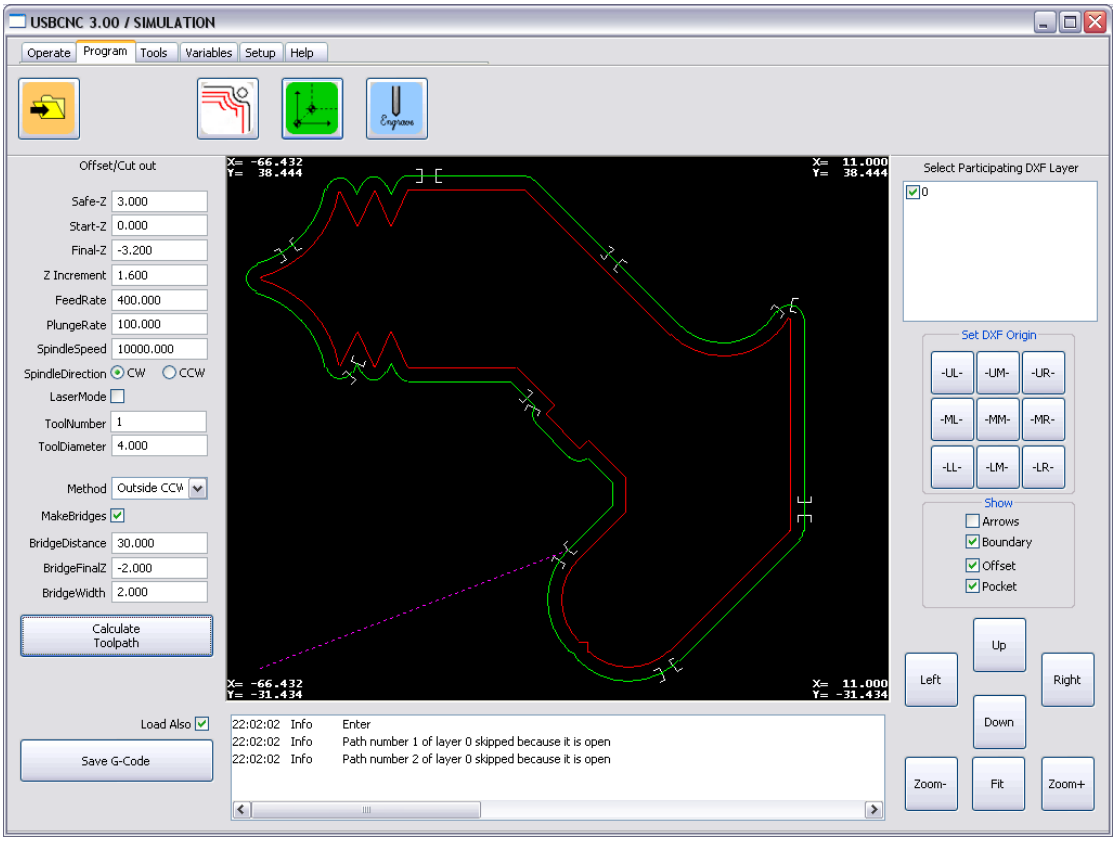
Parameters involved:

Save-Z	When moving from one region to another, the machine goes to this height.
Start-Z	Z value where the tool touches the material to be machined.
Final-Z	Z value specifying the milling depth lowest Z value. Final Z must be lower than Start Z.
Z Increment	This specifies the step size when machining in passes.
Feed rate	Milling feed (F) in mm/min
Plunge rate	Feed (F) that the Z moves down into the material also mm/min
Spindle speed	S value for spindle.
CW/CCW	Spindle direction (M3/M4)
Tool number	This is only used for the M6 tool change command
Tool Diameter	Diameter of the tool for the offset and pocketing calculations.
Method	Outside/inside/clockwise/counterclockwise operation
Finish allowance.	Material that is left for the finishing pass when pocketing. This finishing pass is at full depth for getting a clean edge.
Step size	Step oversize for pocketing, this value should be lower than the tool diameter.
Laser mode	For profiling, when switched on, the tool will be switched off when moving from one region to another.
Make bridges	Leave small pieces of material, that prevent you object from falling out (and get damaged) when profiling.
Bridge distance	Approx distance, the exact distance is calculated such that all bridges have equal distance.

BridgeFinalZ	Lowest Z value for bridge, this value should be between startZ and finalZ
BridgeWidth	The width of a bridge.

When the parameters are set, press calculate tool path, it will be visualized on the screen.

Here an example of profiling with bridges:



Note: The offset and pocket calculation might not always work, this is usually because of small errors in the drawing like lines over each other or not connecting lines. A more robust offset/pocket calculation is in progress.

The engraving function is robust and will always work.

2.8 KEYBOARD SHORTCUTS

Besides the already explained keys for jogging etc, there are a few extra, these are special for pendant builders.

```
Alt-gr + g = run/pause
       + r = reset
       + s = start/stop spindle
       + m = start/stop mist coolant
       + f = start/stop flood coolant
       + 1 = +feed
       + 2 = -feed
       + 3 = +Speed
       + 4 = -Speed
       + 5 .. + 9 =  Zero axis 1 .. Zero axis 5
```

3 Input: the RS274/NGC Language

This section describes the input language, RS274/NGC.

3.1 OVERVIEW

The RS274/NGC language is based on lines of code. Each line (also called a "block") may include commands to a machining center to do several different things. Lines of code may be collected in a file to make a program.

A typical line of code consists of an optional line number at the beginning followed by one or more "words." A word consists of a letter followed by a number (or something that evaluates to a number). A word may either give a command or provide an argument to a command. For example, "G1 X3" is a valid line of code with two words. "G1" is a command meaning "move in a straight line at the programmed feed rate," and "X3" provides an argument value (the value of X should be 3 at the end of the move). Most RS274/NGC commands start with either G or M (for miscellaneous). The words for these commands are called "G codes" and "M codes."

The RS274/NGC language has no indicator for the start of a program. The RS274/NGC language has two commands (M2 or M30), either of which ends a program.

3.2 RS274/NGC LANGUAGE VIEW OF A MACHINING CENTER

The RS274/NGC language is based on a particular view of what a machining center to be controlled is like. The view is as described in Section 2.1, with the changes described below. The RS274/NGC language view includes one mechanical component not known to the canonical machining functions: a cycle start button. The use of the button is described in Section 3.6.1.

The RS274/NGC language contains commands that change the way subsequent commands are to be interpreted, but do not tell the machining center to do anything. These are not covered in this section, but are dealt with as they arise in Section 3.5.17, Section 3.5.19, and Section 3.5.20.

3.2.1 Parameters

In the RS274/NGC language view, a machining center maintains an array of 5400 numerical parameters. Many of them have specific uses. The parameter array should persist over time, even if the machining center is powered down. USBCN stores the parameters that have specific use only. This is performed when the user presses the “Save Fixtures” button in the variable view. The specific parameters are listed in the table below. Other parameters in range of 1..5400 are free to use in your G-Code program.

```
A simple example of usage:
#1=100 ; assign the value 100 to variable #1
G0[#1] ; use #1 to move to 100
```

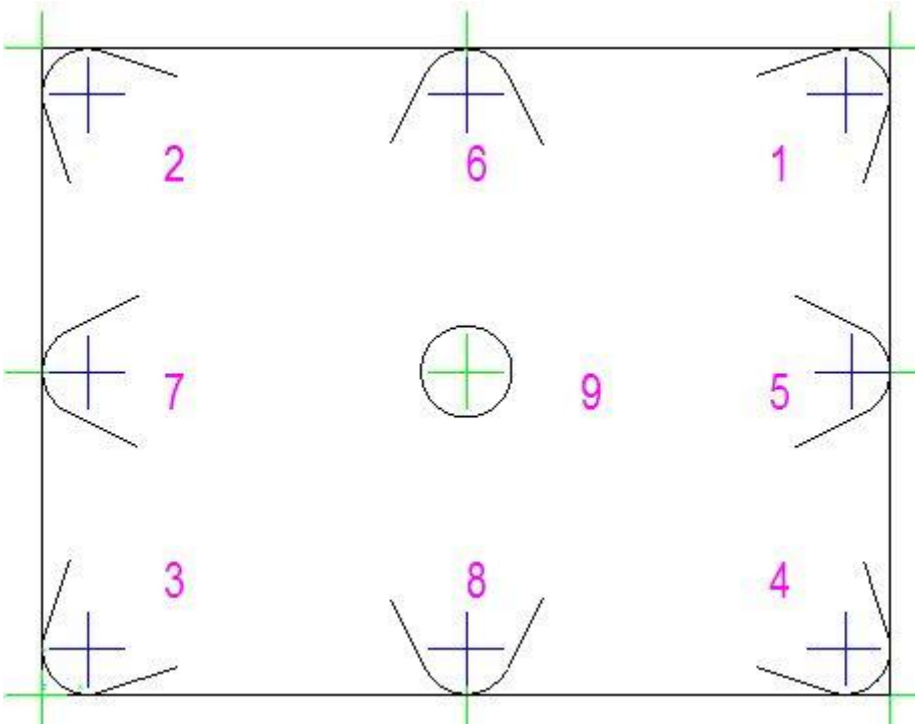
Parameter number	Meaning
5001-5006	POS X – C, interpreter position = work position
5008	Actual TOOL #
5009	Actual TOOL Radius
5010	Actual TOOL Z offset
5011	New tool during tool change
5012	Actual tool X offset
5051 - 5056	Probe position X – C in machine coordinates
5061 - 5066	Probe position X – C in work coordinates
5067	1 if probe is triggered after G38.2, 0 otherwise.
5068	Actual Probe value
5161 - 5166	G28 home X - C
5181 - 5186	G30 home X - C
5211 - 5216	G92 offset X - C
5220	Coord. System number
5221 - 5226	Coord. System 1 X – C
5241 - 5246	Coord. System 2 X – C
5261 - 5266	Coord. System 3 X – C
5281 - 5286	Coord. System 4 X – C
5301 - 5306	Coord. System 5 X – C
5321 - 5326	Coord. System 6 X – C
5341 - 5346	Coord. System 7 X – C
5361 - 5366	Coord. System 8 X – C
5381 - 5386	Coord. System 9 X – C
5401 – 5416	Tool z offset (Length) Tool 1 – Tool 16
5501 – 5516	Tool diameter Tool 1 – Tool 16
5601 – 5616	Tool x offset (for Turning) Tool 1 – Tool 16
	(Currently supported only Tool 0 .. Tool 16)

3.2.2 Tool data

Tool ID	zOffset (Length)	xOffset (For turning)	Diameter	orientation
1				1-9
2				1-9
..				..
16				
				1-9

3.2.2.1 TOOL ORIENTATION FOR LATHES

When the G18 plane (X-Z) is selected, special LATHE tool radius compensation can be used (G41, G42). Depending on the tool orientation and tool radius an extra offset is applied.



The blue crosses show the radius center of the tool.
The green crosses show the controlled point depending on the tool orientation. For orientation = 9 there is no offset compensation. For orientation = 2, the compensation in X is –tool radius, in Z also –tool radius.

3.2.3 Coordinate Systems

In the RS274/NGC language view, a machining center has an absolute coordinate system and nine program coordinate systems.

You can set the offsets of the nine program coordinate systems using G10 L2 Pn (n is the number of the coordinate system) with values for the axes in terms of the absolute coordinate system.

You can select one of the nine systems by using G54, G55, G56, G57, G58, G59, G59.1, G59.2, or G59.3 (see Section 3.5.13). It is not possible to select the absolute coordinate system directly.

You can offset the current coordinate system using G92 or G92.3. This offset will then apply to all nine program coordinate systems. This offset may be cancelled with G92.1 or G92.2. See Section 3.5.18.
You can make straight moves in the absolute machine coordinate system by using G53 with either G0 or G1.

Data for coordinate systems is stored in parameters, see the previous section.
During initialization, the coordinate system is selected that is specified by parameter 5220. A value of 1 means the first coordinate system (the one G54 activates), a value of 2 means the second coordinate system (the one G55 activates), and so on. It is an error for the value of parameter 5220 to be anything but a whole number between one and nine.

3.3 FORMAT OF A LINE

A permissible line of input RS274/NGC code consists of the following, in order, with the restriction that there is a maximum (currently 256) to the number of characters allowed on a line.

- An optional line number.
- Any number of words, parameter settings, and comments.

Any input not explicitly allowed is illegal and will cause the Interpreter to signal an error. Spaces and tabs are allowed anywhere on a line of code and do not change the meaning of the line, except inside comments. This makes some strange-looking input legal. The line "g0x +0. 12 34y 7" is equivalent to "g0 x+0.1234 y7", for example.

Blank lines are allowed in the input. They are to be ignored.
Input is case insensitive.

3.3.1 Line Number

A line number is the letter N followed by an integer (with no sign) between 0 and 99999 written with no more than five digits (000009 is not OK, for example). Line numbers may be repeated or used out of order, although normal practice is to avoid such usage.
Line numbers may also be skipped, and that is normal practice. A line number is not required to be used, but must be in the proper place if used.

3.3.2 Word

A word is a letter other than N followed by a real value.
Words may begin with any of the letters shown in Table 3-2. The table includes N for completeness, even though, as defined above, line numbers are not words. Several letters (I, J, K, L, P, and R) may have different meanings in different contexts.

Letter	Meaning
A	A-axis of machine
D	Tool radius compensation number
F	Feed rate
G	General function (see Table 3-4)
H	Tool length offset index
I	X-axis offset for arcs X offset in G87 canned cycle
J	Y-axis offset for arcs Y offset in G87 canned cycle
K	Z-axis offset for arcs Z offset in G87 canned cycle
L	number of repetitions in canned cycles key used with G10
M	miscellaneous function (see Table 3-6)

Letter	Meaning
N	line number
P	dwell time in canned cycles dwell time with G4 key used with G10
Q	feed increment in G83 canned cycle
R	arc radius, clear_z distance in canned cycle
S	spindle speed
T	tool selection
X	X-axis of machine
Y	Y-axis of machine
Z	Z-axis of machine

A real value is some collection of characters that can be processed to come up with a number. A real value may be an explicit number (such as 341 or -0.8807), a parameter value, an expression, or a unary operation value. Definitions of these follow immediately. Processing characters to come up with a number is called "evaluating". An explicit number evaluates to itself.

3.3.2.1 NUMBER

The following rules are used for (explicit) numbers. In these rules a digit is a single character between 0 and 9.

- A number consists of (1) an optional plus or minus sign, followed by (2) zero to many digits, followed, possibly, by (3) one decimal point, followed by (4) zero to many digits - provided that there is at least one digit somewhere in the number.
- There are two kinds of numbers: integers and decimals. An integer does not have a decimal point in it; a decimal does.
- Numbers may have any number of digits, subject to the limitation on line length. Only about seventeen significant figures will be retained, however (enough for all known applications).
- A non-zero number with no sign as the first character is assumed to be positive.

Notice that initial (before the decimal point and the first non-zero digit) and trailing (after the decimal point and the last non-zero digit) zeros are allowed but not required.
A number written with initial or trailing zeros will have the same value when it is read as if the extra zeros were not there.

Numbers used for specific purposes in RS274/NGC are often restricted to some finite set of values or some to some range of values. In many uses, decimal numbers must be close to integers; this includes the values of indexes (for parameters and carousel slot numbers, for example), M codes, and G codes multiplied by ten. A decimal number which is supposed be close to an integer is considered close enough if it is within 0.0001 of an integer.

3.3.2.2 PARAMETER VALUE

A parameter value is the pound character # followed by a real value. The real value must evaluate to an integer between 1 and 5399. The integer is a parameter number, and the value of the parameter value is whatever number is stored in the numbered parameter.
The # character takes precedence over other operations, so that, for example, "#1+2" means the number found by adding 2 to the value of parameter 1, not the value found in parameter 3. Of course, #[1+2] does mean the value found in parameter 3. The # character may be repeated; for example ##2 means the value of the parameter whose index is the (integer) value of parameter 2.

3.3.2.3 EXPRESSIONS AND BINARY OPERATIONS

An expression is a set of characters starting with a left bracket [and ending with a balancing right bracket]. In between the brackets are numbers, parameter values, mathematical operations, and other expressions. An expression may be evaluated to produce a number. The expressions on a line are evaluated when the line is read, before anything on the line is executed. An example of an expression is [1 + acos[0] - [#3 ** [4.0/2]]].

Binary operations appear only inside expressions. Nine binary operations are defined. There are four basic mathematical operations: addition (+), subtraction (-), multiplication (*), and division (/). There are three logical operations: non-exclusive or (OR), exclusive or (XOR), and logical and (AND). The eighth operation is the modulus operation (MOD). The ninth operation is the "power" operation (**) of raising the number on the left of the operation to the power on the right.

The binary operations are divided into three groups. The first group is: power. The second group is: multiplication, division, and modulus. The third group is: addition, subtraction, logical non-exclusive or, logical exclusive or, and logical and. If operations are strung together (for example in the expression [2.0 / 3 * 1.5 - 5.5 / 11.0]), operations in the first group are to be performed before operations in the second group and operations in the second group before operations in the third group. If an expression contains more than one operation from the same group (such as the first / and * in the example), the operation on the left is performed first. Thus, the example is equivalent to: [((2.0 / 3) * 1.5) - (5.5 / 11.0)] , which simplifies to [1.0 - 0.5] , which is 0.5.

The logical operations and modulus are to be performed on any real numbers, not just on integers. The number zero is equivalent to logical false, and any non-zero number is equivalent to logical true.

3.3.2.4 UNARY OPERATION VALUE

A unary operation value is either "ATAN" followed by one expression divided by another expression (for example "ATAN[2]/[1+3]") or any other unary operation name followed by an expression (for example "SIN[90]"). The unary operations are: ABS (absolute value), ACOS (arc cosine), ASIN (arc sine), ATAN (arc tangent), COS (cosine), EXP (e raised to the given power), FIX (round down), FUP (round up), LN (natural logarithm), ROUND (round to the nearest whole number), SIN (sine), SQRT (square root), and TAN (tangent). Arguments to unary operations which take angle measures (COS, SIN, and TAN) are in degrees. Values returned by unary operations which return angle measures (ACOS, ASIN, and ATAN) are also in degrees.

The FIX operation rounds towards the left (less positive or more negative) on a number line, so that FIX[2.8] =2 and FIX[-2.8] = -3, for example. The FUP operation rounds towards the right (more positive or less negative) on a number line; FUP[2.8] = 3 and FUP[-2.8] = -2, for example.

3.3.3 Parameter Setting

A parameter setting is the following four items one after the other: (1) a pound character # , (2) a real value which evaluates to an integer between 1 and 5399, (3) an equal sign = , and (4) a real value. For example "#3 = 15" is a parameter setting meaning "set parameter 3 to 15."

A parameter setting does not take effect until after all parameter values on the same line have been found. For example, if parameter 3 has been previously set to 15 and the line "#3=6 G1 x#3" is interpreted, a straight move to a point where x equals 15 will occur and the value of parameter 3 will be 6.

3.3.4 Comments and Messages

Printable characters and white space inside parentheses is a comment. A left parenthesis always starts a comment. The comment ends at the first right parenthesis found thereafter. Once a left parenthesis is placed on a line, a matching right parenthesis must appear before

the end of the line. Comments may not be nested; it is an error if a left parenthesis is found after the start of a comment and before the end of the comment.
Here's an example of a line containing a comment: "G80 M5 (stop motion)". Comments do not cause a machining center to do anything.

A comment contains a message if "MSG," appears after the left parenthesis and before any other printing characters. Variants of "MSG," which include white space and lower case characters are allowed. The rest of the characters before the right parenthesis are considered to be a message. Messages should be displayed on the message display device. Comments not containing messages need not be displayed there.

3.3.5 Item Repeats

A line may have any number of G words, but two G words from the same modal group (see Section 3.4) may not appear on the same line.

A line may have zero to four M words. Two M words from the same modal group may not appear on the same line.

For all other legal letters, a line may have only one word beginning with that letter.

If a parameter setting of the same parameter is repeated on a line, "#3=15 #3=6", for example, only the last setting will take effect. It is silly, but not illegal, to set the same parameter twice on the same line.

If more than one comment appears on a line, only the last one will be used; each of the other comments will be read and its format will be checked, but it will be ignored thereafter. It is expected that putting more than one comment on a line will be very rare.

3.3.6 Item order

The three types of item whose order may vary on a line (as given at the beginning of this section) are word, parameter setting, and comment. Imagine that these three types of item are divided into three groups by type.

The first group (the words) may be reordered in any way without changing the meaning of the line.

If the second group (the parameter settings) is reordered, there will be no change in the meaning of the line unless the same parameter is set more than once. In this case, only the last setting of the parameter will take effect. For example, after the line "#3=15 #3=6" has been interpreted, the value of parameter 3 will be 6. If the order is reversed to "#3=6 #3=15" and the line is interpreted, the value of parameter 3 will be 15.

If the third group (the comments) contains more than one comment and is reordered, only the last comment will be used.

If each group is kept in order or reordered without changing the meaning of the line, then the three groups may be interleaved in any way without changing the meaning of the line. For example, the line "g40 g1 #3=15 (foo) #4=-7.0" has five items and means exactly the same thing in any of the 120 possible orders (such as "#4=-7.0 g1 #3=15 g40 (foo)") for the five items.

3.3.7 Commands and Machine Modes

In RS274/NGC, many commands cause a machining center to change from one mode to another, and the mode stays active until some other command changes it implicitly or explicitly. Such commands are called "modal". For example, if coolant is turned on, it stays on

until it is explicitly turned off. The G codes for motion are also modal. If a G1 (straight move) command is given on one line, for example, it will be executed again on
the next line if one or more axis words are available on the line, unless an explicit command is given on that next line using the axis words or cancelling motion.

"Non-modal" codes have effect only on the lines on which they occur. For example, G4 (dwell) is non-modal.

3.4 MODAL GROUPS

Modal commands are arranged in sets called "modal groups", and only one member of a modal group may be in force at any given time. In general, a modal group contains commands for which it is logically impossible for two members to be in effect at the same time - like measure in inches vs. measure in millimeters. A machining center may be in many modes at the same time, with one mode from each modal group being in effect. The modal groups are shown in Table 3-3.

Table 3-3 Modal Groups

The modal groups for G codes are: group 1 = {G0, G1, G2, G3, G38.2, G76, G80, G81, G82, G83, G84, G85, G86, G87, G88, G89} motion group 2 = {G17, G18, G19} plane selection group 3 = {G90, G91} distance mode group 5 = {G93, G94} feed rate mode group 6 = {G20, G21} units group 7 = {G40, G41, G42} cutter radius compensation group 8 = {G43, G49} tool length offset group 10 = {G98, G99} return mode in canned cycles group 12 = {G54, G55, G56, G57, G58, G59, G59.1, G59.2, G59.3} coordinate system selection group 13 = {G61, G61.1, G64} path control mode
The modal groups for M codes are: group 4 = {M0, M1, M2, M30, M60} stopping group 5 = {M64, M65, M66} general purpose I/O group 6 = {M6} tool change group 7 = {M3, M4, M5} spindle turning group 8 = {M7, M8, M9} coolant (special case: M7 and M8 may be active at the same time) group 9 = {M48, M49} enable/disable feed and speed override switches
In addition to the above modal groups, there is a group for non-modal G codes: group 0 = {G4, G10, G28, G30, G53, G92, G92.1, G92.2, G92.3}

For several modal groups, when a machining center is ready to accept commands, one member of the group must be in effect. There are default settings for these modal groups. When the machining center is turned on or otherwise re-initialized, the default values are automatically in effect.

Group 1, the first group on the table, is a group of G codes for motion. One of these is always in effect. That one is called the current motion mode.

It is an error to put a G-code from group 1 and a G-code from group 0 on the same line if both of them use axis words. If an axis word-using G-code from group 1 is implicitly in effect on a line (by having been activated on an earlier line), and a group 0 G-code that uses axis words appears on the line, the activity of the group 1 G-code is suspended for that line. The axis word-using G-codes from group 0 are G10, G28, G30, and G92.

3.5 G CODES

G codes of the RS274/NGC language are shown in Table 3-4 and described in this Section.

The descriptions contain command prototypes, set in **bold** type.
In the command prototypes, three dots (…) stand for a real value. As described earlier, a real value may be (1) an explicit number, 4, for example, (2) an expression**, [2+2]**, for example, (3) a parameter value, **#88**, for example, or (4) a unary function value, acos[0], for example.
In most cases, if axis words (any or all of **X…, Y…, Z…, A…, B…, C…**) are given, they specify a destination point. Axis numbers are in the currently active coordinate system, unless explicitly described as being in the absolute coordinate system. Where axis words are optional, any omitted axes will have their current value. Any items in the command prototypes not explicitly described as optional are required. It is an error if a required item is omitted.

In the prototypes, the values following letters are often given as explicit numbers. Unless stated otherwise, the explicit numbers can be real values. For example, **G10 L2** could equally well be written **G[2*5] L[1+1]**. If the value of parameter 100 were 2, **G10 L#100** would also mean the same. Using real values which are not explicit numbers as just shown in the examples is rarely useful.

If **L…** is written in a prototype the "…" will often be referred to as the "L number". Similarly the "…" in **H…** may be called the "H number", and so on for any other letter.

3.5.1 Rapid Linear Motion - G0

For rapid linear motion, program **G0 X… Y… Z… A…**, where all the axis words are optional, except that at least one must be used. The G0 is optional if the current motion mode is G0. This will produce coordinated linear motion to the
destination point at the current traverse rate (or slower if the machine will not go that fast). It is expected that cutting will not take place when a G0 command is executing.

It is an error if:
• All axis words are omitted.

If cutter radius compensation is active, the motion will differ from the above; see Appendix A. If G53 is programmed on the same line, the motion will also differ; see Section 3.5.12.

Table 3-4 G Codes

G Code	Meaning
G0	rapid positioning
G1	linear interpolation
G2	circular/helical interpolation (clockwise)
G3	circular/helical interpolation (counterclockwise)
G4	dwell
G10	coordinate system origin setting
G17	XY-plane selection
G18	XZ-plane selection
G19	YZ-plane selection
G20	inch system selection
G21	millimeter system selection
G28	move to park position 1, setup on variable page
G30	move to park position 2, setup on variable page
G33	Lathe, motion synchronized to spindle
G38.2	straight probe
G40	cancel cutter radius compensation
G41	start cutter radius compensation left
G42	start cutter radius compensation right
G43	tool length offset (plus) , tool X offset for lathe
G49	cancel tool length offset
G53	motion in machine coordinate system
G54	use preset work coordinate system 1
G55	use preset work coordinate system 2
G56	use preset work coordinate system 3
G57	use preset work coordinate system 4
G58	use preset work coordinate system 5
G59	use preset work coordinate system 6
G59.1	use preset work coordinate system 7
G59.2	use preset work coordinate system 8
G59.3	use preset work coordinate system 9
G61	set path control mode: exact path
G61.1	set path control mode: exact stop
G64	set path control mode: continuous
G76	Lathe, threading
G80	cancel motion mode (including any canned cycle)
G81	canned cycle: drilling
G82	canned cycle: drilling with dwell
G83	canned cycle: peck drilling
G84	canned cycle: right hand tapping
G85	canned cycle: boring, no dwell, feed out
G86	canned cycle: boring, spindle stop, rapid out
G87	canned cycle: back boring
G88	canned cycle: boring, spindle stop, manual out
G89	canned cycle: boring, dwell, feed out
G90	absolute distance mode
G91	incremental distance mode
G92	offset coordinate systems and set parameters
G92.1	cancel offset coordinate systems and set parameters to zero
G92.2	cancel offset coordinate systems but do not reset parameters
G92.3	apply parameters to offset coordinate systems
G93	inverse time feed rate mode
G94	units per minute feed rate mode
G98	initial level return in canned cycles
G99	R-point level return in canned cycles

3.5.2 Linear Motion at Feed Rate - G1

For linear motion at feed rate (for cutting or not), program **G1 X… Y… Z… A…**, where all the axis words are optional, except that at least one must be used. The G1 is optional if the current motion mode is G1. This will produce coordinated linear motion to the destination point at the current feed rate (or slower if the machine will not go that fast).

It is an error if:

- All axis words are omitted.

If cutter radius compensation is active, the motion will differ from the above; see Appendix A. If G53 is programmed on the same line, the motion will also differ; see Section 3.5.12.

3.5.3 Arc at Feed Rate - G2 and G3

A circular or helical arc is specified using either G2 (clockwise arc) or G3 (counterclockwise arc). The axis of the circle or helix must be parallel to the X, Y, or Z-axis of the machine coordinate system. The axis (or, equivalently, the plane perpendicular to the axis) is selected with G17 (Z-axis, XY-plane), G18 (Y-axis, XZ-plane), or G19 (X-axis, YZ-plane). If the arc is circular, it lies in a plane parallel to the selected plane.

If a line of RS274/NGC code makes an arc and includes rotational axis motion, the rotational axes turn at a constant rate so that the rotational motion starts and finishes when the XYZ motion starts and finishes. Lines of this sort are hardly ever programmed.
If cutter radius compensation is active, the motion will differ from what is described here. See Appendix A.

Two formats are allowed for specifying an arc. We will call these the center format and the radius format. In both formats the G2 or G3 is optional if it is the current motion mode.

3.5.3.1 RADIUS FORMAT ARC

In the radius format, the coordinates of the end point of the arc in the selected plane are specified along with the radius of the arc. Program **G2 X… Y… Z… A… R…** (or use G3 instead of G2). R is the radius. The axis words are all optional except that at least one of the two words for the axes in the selected plane must be used. The R number is the radius. A positive radius indicates that the arc turns through 180 degrees or less, while a negative radius indicates a turn of 180 degrees to 359.999 degrees. If the arc is helical, the value of the end point of the arc on the coordinate axis parallel to the axis of the helix is also specified.

It is an error if:

- both of the axis words for the axes of the selected plane are omitted,
- the end point of the arc is the same as the current point.

It is not good practice to program radius format arcs that are nearly full circles or are semicircles (or nearly semicircles) because a small change in the location of the end point will produce a much larger change in the location of the center of the circle (and, hence, the middle of the arc). The magnification effect is large enough that rounding error in a number can produce out-of-tolerance cuts. Nearly full circles are outrageously bad, semicircles (and nearly so) are only very bad. Other size arcs (in the range tiny to 165 degrees or 195 to 345 degrees) are OK.

Here is an example of a radius format command to mill an arc: **G17 G2 x 10 y 15 r 20 z 5**.

That means to make a clockwise (as viewed from the positive Z-axis) circular or helical arc whose axis is parallel to the Z-axis, ending where X=10, Y=15, and Z=5, with a radius of 20. If the starting value of Z is 5, this is an arc of a circle parallel to the XY-plane; otherwise it is a helical arc.

3.5.3.2 CENTER FORMAT ARC

In the center format, the coordinates of the end point of the arc in the selected plane are specified along with the offsets of the center of the arc from the current location. In this format, it is OK if the end point of the arc is the same as the current point. It is an error if:

- When the arc is projected on the selected plane, the distance from the current point to the center differs from the distance from the end point to the center by more than 0.0002 inch (if inches are being used) or 0.002 millimeter (if millimeters are being used).

When the XY-plane is selected, program **G2 X… Y… Z… A… I… J…** (or use G3 instead of G2). The axis words are all optional except that at least one of X and Y must be used. I and J are the offsets from the current location (in the X and Y directions, respectively) of the center of the circle. I and J are optional except that at least one of the two must be used. It is an error if:

- X and Y are both omitted,
- I and J are both omitted.

When the XZ-plane is selected, program **G2 X… Y… Z… A… I… K…** (or use G3 instead of G2). The axis words are all optional except that at least one of X and Z must be used. I and K are the offsets from the current location (in the X and Z directions, respectively) of the center of the circle. I and K are optional except that at least one of the two must be used. It is an error if:

- X and Z are both omitted,
- I and K are both omitted.

When the YZ-plane is selected, program **G2 X… Y… Z… A… B… C… J… K…** (or use G3 instead of G2). The axis words are all optional except that at least one of Y and Z must be used. J and K are the offsets from the current location (in the Y and Z directions, respectively) of the center of the circle. J and K are optional except that at least one of the two must be used. It is an error if:

- Y and Z are both omitted,
- J and K are both omitted.

Here is an example of a center format command to mill an arc: **G17 G2 x 10 y 16 i 3j 4 z 9**.

That means to make a clockwise (as viewed from the positive z-axis) circular or helical arc whose axis is parallel to the Z-axis, ending where X=10, Y=16, and Z=9, with its center offset in the X direction by 3 units from the current X location and offset in the Y direction by 4 units from the current Y location. If the current location has X=7, Y=7 at the outset, the center will be at X=10, Y=11. If the starting value of Z is 9, this is a circular arc; otherwise it is a helical arc. The radius of this arc would be 5.

In the center format, the radius of the arc is not specified, but it may be found easily as the distance from the center of the circle to either the current point or the end point of the arc.

3.5.4 Dwell - G4

For a dwell, program G4 P… . This will keep the axes unmoving for the period of time in seconds specified by the P number. It is an error if:

- the P number is negative.

3.5.5 Set Coordinate System Data -G10

To set the coordinate values for the origin of a coordinate system, program **G10 L2 P … X… Y… Z… A…**, where the P number must evaluate to an integer in the range 1 to 9 (corresponding to G54 to G59.3) and all axis words are optional. The coordinates of the origin of the coordinate system specified by the P number are reset to the coordinate values given

(in terms of the absolute coordinate system). Only those coordinates for which an axis word is included on the line will be reset.

It is an error if:

- the P number does not evaluate to an integer in the range 1 to 9.

If origin offsets (made by G92 or G92.3) were in effect before G10 is used, they will continue to be in effect afterwards.

The coordinate system whose origin is set by a G10 command may be active or inactive at the time the G10 is executed.
Example:**G10 L2 P1 x 3.5 y 17.2** sets the origin of the first coordinate system (the one selected by G54) to a point where X is 3.5 and Y is 17.2 (in absolute coordinates). The Z coordinate of the origin (and the coordinates for any rotational axes) are whatever those coordinates of the origin were before the line was executed.

3.5.6 Plane Selection - G17, G18, and G19

Program **G17** to select the XY-plane, **G18** to select the XZ-plane, or **G19** to select the YZ-plane. The effects of having a plane selected are discussed in Section 3.5.3 and Section 3.5.16.

3.5.7 Length Units - G20/G21 and G70/G71

Program G20 to use inches for length units. Program G21 to use millimeters.
It is usually a good idea to program either G20 or G21 near the beginning of a program before any motion occurs, and not to use either one anywhere else in the program. It is the responsibility of the user to be sure all numbers are appropriate for use with the current length units. G70/G71 is added for CAM software compatibility.

3.5.8 Return to Home - G28 and G30

Two home positions are defined (by parameters 5161-5166 for G28 and parameters 5181-5186 for G30). The parameter values are in terms of the absolute coordinate system, but are in unspecified length units.
To return to home position by way of the programmed position, program **G28 X… Y… Z… A…** (or use G30). All axis words are optional. The path is made by a traverse move from the current position to the programmed position, followed by a traverse move to the home position. If no axis words are programmed, the intermediate point is the current point, so only one move is made.

3.5.9 G33, G33.1 Spindle-Synchronized Motion

For spindle-synchronized motion in one direction, program **G33 X… Y… Z… K…** where K gives the distance moved in XYZ for each revolution of the spindle. For instance, if starting at Z=0, G33 Z-1 K.0625 produces a 1 inch motion in Z over 16 revolutions of the spindle. This command might be part of a program to produce a 16TPI thread.
A move to the specified coordinate, synchronized with the spindle at the given ratio and starting with a spindle index pulse

All the axis words are optional, except that at least one must be used.
It is an error if:

- all axis words are omitted.
- the spindle is not turning when this command is executed
- the requested linear motion exceeds machine velocity limits due to the spindle speed

3.5.10 Straight Probe - G38.2

3.5.10.1 THE STRAIGHT PROBE COMMAND

Program **G38.2 X… Y… Z… A…** to perform a straight probe operation. The rotational axis words are allowed, but it is better to omit them. If rotational axis words are used, the numbers must be the same as the current position numbers so that the rotational axes do not move. The linear axis words are optional, except that at least one of them must be used. The tool in the spindle must be a probe.
It is an error if:

- the current point is less than 0.254 millimeter or 0.01 inch from the programmed point.
- G38.2 is used in inverse time feed rate mode,
- any rotational axis is commanded to move,
- no X, Y, or Z-axis word is used.

In response to this command, the machine moves the controlled point (which should be at the end of the probe tip) in a straight line at the current feed rate toward the programmed point. If the probe trips, the probe is retracted slightly from the trip point at the end of command execution. If the probe does not trip even after overshooting the programmed point slightly, an error is signaled.

After successful probing, parameters 5061 to 5066 will be set to the program coordinates of the location of the controlled point at the time the probe tripped. The variables 5051 to 5056 will contain the machine coordinates. Useful for measuring tools in absolute machine positions. G53 G38.2 will move in machine coordinates.

3.5.10.2 USING THE STRAIGHT PROBE COMMAND

Using the straight probe command, if the probe shank is kept nominally parallel to the Z-axis (i.e., any rotational axes are at zero) and the tool length offset for the probe is used, so that the controlled point is at the end of the tip of the probe:

- without additional knowledge about the probe, the parallelism of a face of a part to the XY-plane may, for example, be found.
- if the probe tip radius is known approximately, the parallelism of a face of a part to the YZ or XZ-plane may, for example, be found.
- if the shank of the probe is known to be well-aligned with the Z-axis and the probe tip radius is known approximately, the center of a circular hole, may, for example, be found.
- if the shank of the probe is known to be well-aligned with the Z-axis and the probe tip radius is known precisely, more uses may be made of the straight probe command, such as finding the diameter of a circular hole.

If the straightness of the probe shank cannot be adjusted to high accuracy, it is desirable to know the effective radii of the probe tip in at least the +X, -X, +Y, and -Y directions. These quantities can be stored in parameters either by being included in the parameter file or by being set in an RS274/NGC program.
Using the probe with rotational axes not set to zero is also feasible. Doing so is more complex than when rotational axes are at zero, and we do not deal with it here.

3.5.10.3 EXAMPLE CODE

As a usable example, the code for finding the center and diameter of a circular hole is shown in Table 3-5. For this code to yield accurate results, the probe shank must be well-aligned with the Z-axis, the cross section of the probe tip at its widest point must be very circular, and the probe tip radius (i.e., the radius of the circular cross section) must be known precisely. If the probe tip radius is known only approximately (but the other conditions hold), the location of the hole center will still be accurate, but the hole diameter will not.

In Table 3-5, an entry of the form <description of number> is meant to be replaced by an actual number that matches the description of number. After this section of code has executed, the X-value of the center will be in parameter 1041, the Y-value of the center in

parameter 1022, and the diameter in parameter 1034. In addition, the diameter parallel to the X-axis will be in parameter 1024, the diameter parallel to the Y-axis in parameter 1014, and the difference (an indicator of circularity) in parameter 1035. The probe tip will be in the hole at the XY center of the hole.

The example does not include a tool change to put a probe in the spindle. Add the tool change code at the beginning, if needed.

Table 3-5 Code to Probe Hole

```
N010 (probe to find center and diameter of circular hole)
N020 (This program will not run as given here. You have to)
N030 (insert numbers in place of <description of number>.)
N040 (Delete lines N020, N030, and N040 when you do that.)
N050 G0 Z <Z-value of retracted position> F <feed rate>
N060 #1001=<nominal X-value of hole center>
N070 #1002=<nominal Y-value of hole center>
N080 #1003=<some Z-value inside the hole>
N090 #1004=<probe tip radius>
N100 #1005=[<nominal hole diameter>/2.0 - #1004]
N110 G0 X#1001 Y#1002 (move above nominal hole center)
N120 G0 Z#1003 (move into hole - to be cautious, substitute G1 for G0 here)
N130 G38.2 X[#1001 + #1005] (probe +X side of hole)
N140 #1011=#5061 (save results)
N150 G0 X#1001 Y#1002 (back to center of hole)
N160 G38.2 X[#1001 - #1005] (probe -X side of hole)
N170 #1021=[[#1011 + #5061] / 2.0] (find pretty good X-value of hole center)
N180 G0 X#1021 Y#1002 (back to center of hole)
N190 G38.2 Y[#1002 + #1005] (probe +Y side of hole)
N200 #1012=#5062 (save results) N210 G0 X#1021 Y#1002 (back to center of hole)
N220 G38.2 Y[#1002 - #1005] (probe -Y side of hole)
N230 #1022=[[#1012 + #5062] / 2.0] (find very good Y-value of hole center)
N240 #1014=[#1012 - #5062 + [2 * #1004]] (find hole diameter in Y-direction)
N250 G0 X#1021 Y#1022 (back to center of hole)
N260 G38.2 X[#1021 + #1005] (probe +X side of hole)
N270 #1031=#5061 (save results)
N280 G0 X#1021 Y#1022 (back to center of hole)
N290 G38.2 X[#1021 - #1005] (probe -X side of hole)
N300 #1041=[[#1031 + #5061] / 2.0] (find very good X-value of hole center)
N310 #1024=[#1031 - #5061 + [2 * #1004]] (find hole diameter in X-direction)
N320 #1034=[[#1014 + #1024] / 2.0] (find average hole diameter)
N330 #1035=[#1024 - #1014] (find difference in hole diameters)
N340 G0 X#1041 Y#1022 (back to center of hole)
N350 M2 (that's all, folks)
```

3.5.11 Cutter Radius Compensation - G40, G41, G41.1, G42, G42.1

To turn cutter radius compensation off, program G40. It is OK to turn compensation off when it is already off. Cutter radius compensation may be performed only if the XY-plane is active.

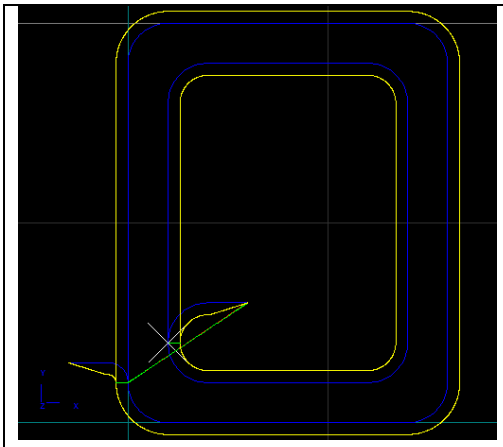
To turn cutter radius compensation on **left** (i.e., the cutter stays to the left of the programmed path when the tool radius is positive), program **G41 D…** . To turn cutter radius compensation on **right** (i.e., the cutter stays to the right of the programmed path when the tool radius is positive), program **G42 D…** . The D word is optional; if there is no D word, the radius of the tool currently in the spindle will be used. If used, the D number should normally be the slot number of the tool in the spindle, although this is not required. It is OK for the D number to be zero; a radius value of zero will be used.

It is an error if:

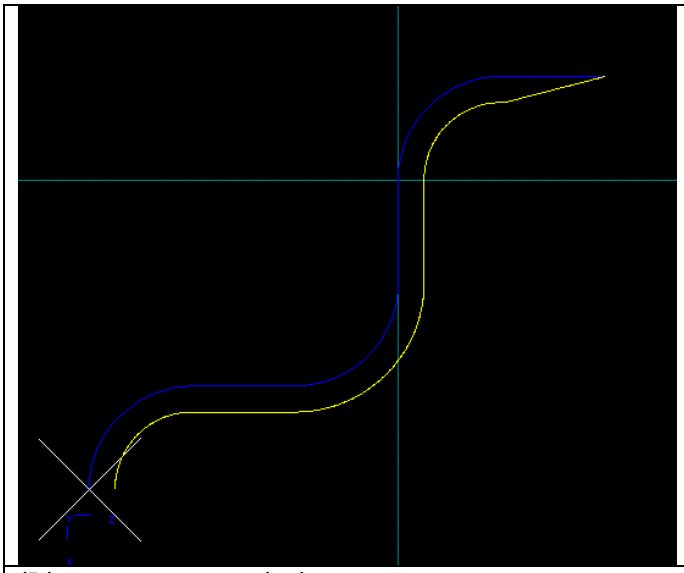
- the D number is not an integer, is negative or is larger than the number of carousel slots,
- the XY-plane is not active or for turning the ZX plane is not active,
- cutter radius compensation is commanded to turn on when it is already on.

The behavior of the machining center when cutter radius compensation is on is described in Appendix A.
With G41.1 D… is the same as G41 D… except now the D number is not a tool number but a tool diameter.
With G42.1 D… is the same as G42 D… except now the D number is not a tool number but a tool diameter.

3.5.11.1 EXAMPLE CODE FOR MILLING

	This example mills out a rectangular object from the outside and inside. On the outside we use G42, tool radius compensation right and for the inside G41, tool radius compensation left is used. For both contours a tool-radius-compensation entry move is programmed consisting of a line which must be longer than the tool-radius used and a circle, of which also the radius is bigger than the tool. By the way, all arc radii should be bigger than the tool radius. If you have inside corners, there should be always an arc, so that the tool fits.
g0 z3 g0 x-15 y15 f500 /g42.1 D6 g1 x-5 (cutter comp entry move 1) g2 x0 y10 r5 (cutter comp entry move 2) g1 z-3 (plunge down) g3 x10 y0 r10 g1 x70 g3 x80 y10 r10 g1 y90 g3 x70 y100 r10 g1 x10 g3 x0 y90 r10 g1 x0 y10 /g40 g0 z3 g0 x30 y30 /g41.1 d6 g1 x20 g3 x10 y20 r10 g1 z-3 g3 x20 y10 r10 g1 x60 g3 x70 y20 r10 g1 y80 g3 x60 y90 r10 g1 x20 g3 x10 y80 r10 g1 y20 /g40 g0 z3 m30	The G42, G41 and G40 codes are programmed with a / (block delete sign) in front. This makes it easy to debug tool comp programs. The program is loaded with block delete on, this is the blue curve. Then the program is run with block delete off resulting in the yellow curve. It is clear to see what the entry move does.

3.5.11.2 EXAMPLE CODE FOR TURNING

	The movement starts at the right upper corner. The blue line is the programmed contour. The yellow is the contour with tool-radius compensation G41. The first G1 line is the tool comp entry move. You can get this figure by putting a / character in front of the G41/G40 codes. The load the program with block delete on and execute it with block delete off. With block delete on the tool comp is skipped.
(Diameter programming) (Use R word for Arcs) g0 x-20 z20 /g41.1 d5 g1 x-20 z10 g3 x0 z0 r10 g1 x20 g2 x40 z-10 r10 g1 z-20 g3 x60 z-30 r10 /g40 m30	(Radius programming) (Use R word for arc's) g0 x-10 z20 /g41.1 d5 g1 x-10 z10 g3 x0 z0 r10 g1 x10 g2 x20 z-10 r10 g1 z-20 g3 x30 z-30 r10 /g40 m30
(Diameter programming) (Use I,K programming for arc's) g0 x-20 z20 /g41.1 d5 g1 x-20 z10 g3 x0 z0 i10 k0 g1 x20 g2 x40 z-10 i0 k-10 g1 z-20 g3 x60 z-30 i10 k0 /g40 m30	(Radius programming) (Use I,K programming for arc's) g0 x-10 z20 /g41.1 d5 g1 x-10 z10 g3 x0 z0 i10 k0 g1 x10 g2 x20 z-10 i0 k-10 g1 z-20 g3 x30 z-30 i10 k0 /g40 m30

3.5.12 Tool Length Offsets - G43, G43.1, and G49

To use a tool length offset from the tool table, program **G43 H…**, where the H number is the desired index in the tool table. It is expected that all entries in this table will be positive. The H number should be, but does not have to be, the same as the slot number of the tool currently in the spindle. It is OK for the H number to be zero; an offset value of zero will be used.

If the H number is omitted, the actual tool in the spindle is used.

It is an error if:

- the H number is not an integer, is negative, or is larger than the number of carousel slots.

To use dynamic tool compensation (not from the tool-table), use G43.1 I.. K.. where I.. gives the tool X offset (turning) and K.. gives the tool Z offset (for turning and milling)

To use no tool length offset, program **G49**. It is OK to program using the same offset already in use. It is also OK to program using no tool length offset if none is currently being used.

#5401 - #5416 is the tool-Z (length) offset.
#5501 - #5516 is the tool-diameter (length).
#5601 - #5616 is the tool-X (width for turning) offset.
The variables can be modified runtime (in the G-Code file) if needed to compensate for tool-wear.

3.5.13 Move in Absolute Coordinates - G53

For linear motion to a point expressed in absolute coordinates, program **G1 G53 X… Y… Z… A…** (or use G0 instead of G1), where all the axis words are optional, except that at least one must be used. The G0 or G1 is optional if it is the current motion mode. G53 is not modal and must be programmed on each line on which it is intended to be active. This will produce coordinated linear motion to the programmed point. If G1 is active, the speed of motion is the current feed rate (or slower if the machine will not go that fast). If G0 is active, the speed of motion is the current traverse rate (or slower if the machine will not go that fast).

It is an error if:

- G53 is used without G0 or G1 being active,
- G53 is used while cutter radius compensation is on.

3.5.14 Select Coordinate System - G54 to G59.3

To select coordinate system 1, program G54, and similarly for other coordinate systems. The system-number-G-code pairs are: (1-G54), (2-G55), (3-G56), (4-G57), (5-G58), (6-G59), (7-G59.1), (8-G59.2), and (9-G59.3).

It is an error if:

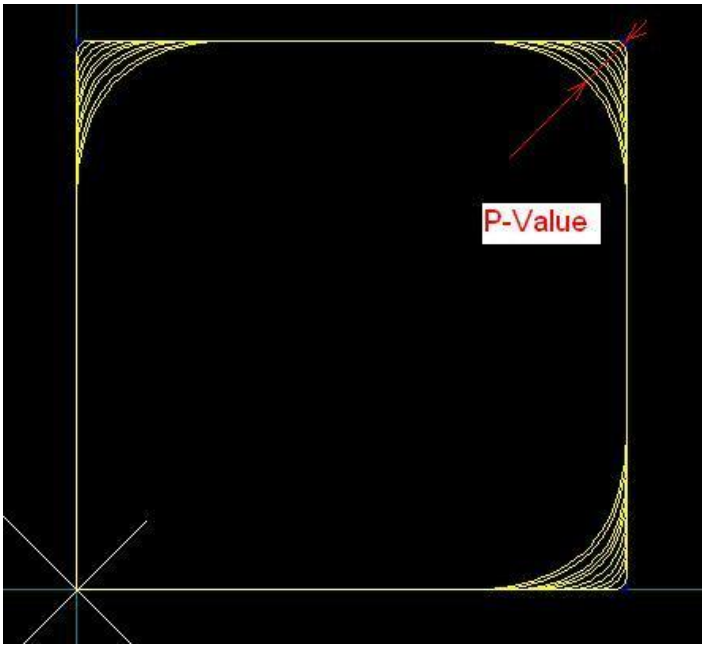
- one of these G-codes is used while cutter radius compensation is on.

3.5.15 Set Path Control Mode - G61, and G64, or G64 Px

Some work pieces require absolute accuracy and some other require nonstop milling for best surface quality. One must understand that it is physically impossible to move around sharp corners without a standstill at the corner. This isn't possible with a car and also not with a CNC machine, since that would require infinite acceleration. The user can make a choice here, absolute accuracy with standstill at every corner (G61) or no standstill and corner round off with specified accuracy (G64Px.x).

G61 puts the machining center into exact path mode, In G61, the motion velocity between motion segments goes to zero, the end position in corners is exactly reached, use this if you require maximum accuracy. When a work piece consists of many small lines this gives a quite vibrating machine because of the continuous acceleration-deceleration-stop behavior.

G64 Px.x for continuous mode. In G64, subsequent moves are blended, when previous move starts to decelerate and reaches a velocity such that the specified accuracy isn't violated, the next move starts to accelerate, the two motions are added. The result is smooth motion with highest possible speed to achieve required accuracy. The corners however are rounded. specifies the distance reached to the corner while blending. The next move is blended with current such that the tool path remains no more than P from the corner. The figure below is a rectangle of 10x10 milled with F 2000. This is done with P values from 0.1 to 1, you can see the impact. This gives the best compromise between accuracy and smooth motion.



Besides the blending, the Px.x parameter with G64 also tries to make bigger G1's (lines) out of lots of small G1's while maintaining the requested accuracy. This makes it possible to move at the highest possible speed. This feature can be very useful when the G-Code is converted from HPGL or by some CAM software package that generates many small line pieces.

The problem with very short line segments as in HPGL or other CAM generated G-Code files.

To make a move from stand still we need to accelerate, then have a certain cruising speed and after decelerate. Short moves typically never reach the requested velocity the accelerate and then at half the distance the decelerate.

This table shows the distance traveled so that the given speed is reached. When the line segments generated by the CAD/CAM program are shorter, the actual speed on the machine will be lower than requested value. Example, you want a milling speed of 900 mm/minute, then

the segments generated by the CAD/CAM program must be smaller than 1.88 mm. If the lines are only 0.21 mm, the feed will go down to 300

Velocity	Feed	Accel	Distance
48	2880	120	19.20
30	1800	120	7.50
25	1500	120	5.21
20	1200	120	3.33
17	1020	120	2.41
15	900	120	1.88
12	720	120	1.20
10	600	120	0.83
9	540	120	0.68
8	480	120	0.53
7	420	120	0.41
6	360	120	0.30
5	300	120	0.21
4	240	120	0.13
3	180	120	0.08

If you machine has higher accelerations which requires bigger motors, also higher milling velocities are possible. The values given here are for a moderate hobby machine. This illustrates that when the G-Code file exists of small segments, e.g. 0.08 mm, that with an acceleration of 120 a feed can be reached of 180 mm/minute at most.

3.5.16 Look Ahead feed

To explain this, I will compare a running CNC machine with driving a race car.
The road maximum velocity signs have to be obeyed and you have to drive your car exactly over the white line in the middle of the road. You will try to reach the maximum allowed velocity where possible. When you see a curve coming up ahead, you will brake so that you will not drift off the road. You will try to look ahead as far as you can see and you take care that you can stop in time if the road suddenly stops.

When you would maintain your speed in sharp curves, you will drift off the road resulting possibly into a car accident. When the road has many short curves, then you will not be able to reach the desired speed. The more PS you have in the car, the higher speed you will reach because you can accelerate faster.

I think this is a good comparison with a CNC machine, the same issues apply. A machine cannot suddenly change velocity, to reach a velocity the motors must accelerate first for a certain time to reach the velocity.

LAF behaves like the ideal racecar driver, it will reach the highest possible velocity without violating the maximum motor accelerations.

There is one additional problem while running CNC programs, some programs consists of short line pieces. When the line pieces connect tangentially (are in line), then LAF will accelerate through over the lines, reaching the maximum allowed speed.
The angle to which LAF considers the segments in line is a setup parameter. The theoretical ideal value would be very small, so that no acceleration value occurs.
More practical values are in the range of 1 to 6 degrees, the experience learns that most machines can handle acceleration spikes up to a certain limit.

The value can be set up to 180 degrees in this case you must know what you are doing, it can be useful during e.g. foam cutting wing profiles. Be aware however that if the curve contains

real sharp angles that step pulse loss may be the result when using large minimum LAF angles.

3.5.17 Threading (Lathe) – G76

G76 P- Z- I- J- R- K- Q- H- E- L-

P Pitch
Z driveline endpoint
I Outside thread diameter, always positive.
J First cut is J beyond I, always positive.
R Depth regression, use 1.0 for constant cutting depths or leave parameter away.
K Full thread depth beyond thread peak, always positive.
Q Compound slide angle, typical 30.
H Additional spring passes at full depth, use 0 for none.
E Taper distance along drive line.
L Taper place, none, enter, exit, both.

;Create a thread from z=20 to z=10, outside diameter=15, inside diameter=14, 10 passes.
G0 X20 Z20
G76 P1.0 Z10 I15 J0.1 K1.0

It is an error if:

- The active plane is not the ZX plane
- Other axis words, such as X- or Y-, are specified
- The R- degression value is less than 1.0.
- All the required words are not specified
- P-, J-, K- or H- is negative
- E- is greater than half the drive line length

The “drive line” is a safe line outside the thread material. The “drive line” goes from the initial location to the Z- value specified with G76. The Z extent of the thread is the same as the drive line.

The “thread pitch”, or distance per revolution, is given by the P- value.

The “thread peak” is given by the I- value, which is an offset from the drive line. Negative I values indicate external threads, and positive I values indicate internal threads. Generally the material has been turned to this size before the G76 cycle.

The “initial cut depth” is given by the J- value. The first threading cut will be J beyond the “thread peak” position. J- is positive, even when I- is negative.

The “full thread depth” is given by the K- value. The final threading cut will be K beyond the “thread peak” position. K- is positive, even when I- is negative.

The “depth degression” is given by the R- value. R1.0 selects constant depth on successive threading passes. R2.0 selects constant area. Values between 1.0 and 2.0 select decreasing depth and increasing area. Values above 2.0 select decreasing area. Beware that unnecessarily high degression values will cause a large number of passes to be used.

The “compound slide angle” Q- is the angle (in degrees) describing to what extent successive passes should be offset along the drive line. This is used to cause one side of the tool to remove more material than the other. A positive Q value causes the leading edge of the tool to cut more heavily. Typical values are 29, 29.5 or 30.

The number of “spring passes” is given by the H- value. Spring passes are additional passes at full thread depth. If no additional passes are desired, program H0.

Tapered entry and exit moves can be programmed using E- and L-. E- gives a distance along the drive line used for the taper. E0.2 will give a taper for the first/last 0.2 length units along the thread. L- is used to specify which ends of the thread get the taper. Program L0 for no taper (the default), L1 for entry taper, L2 for exit taper, or L3 for both entry and exit tapers.

The tool will pause briefly for synchronization before each threading pass, so a relief groove will be required at the entry unless the beginning of the thread is past the end of the material or an entry taper is used.

Unless using an exit taper, the exit move (traverse to original X) is not synchronized to the spindle speed. With a slow spindle, the exit move might take only a small fraction of a revolution. If the spindle speed is increased after several passes are complete, subsequent exit moves will require a larger portion of a revolution, resulting in a very heavy cut during the exit move. This can be avoided by providing a relief groove at the exit, or by not changing the spindle speed while threading.

The sample program g76.ngc shows the use of the G76 canned cycle, and can be previewed and executed on any machine using the sim/lathe.ini configuration.

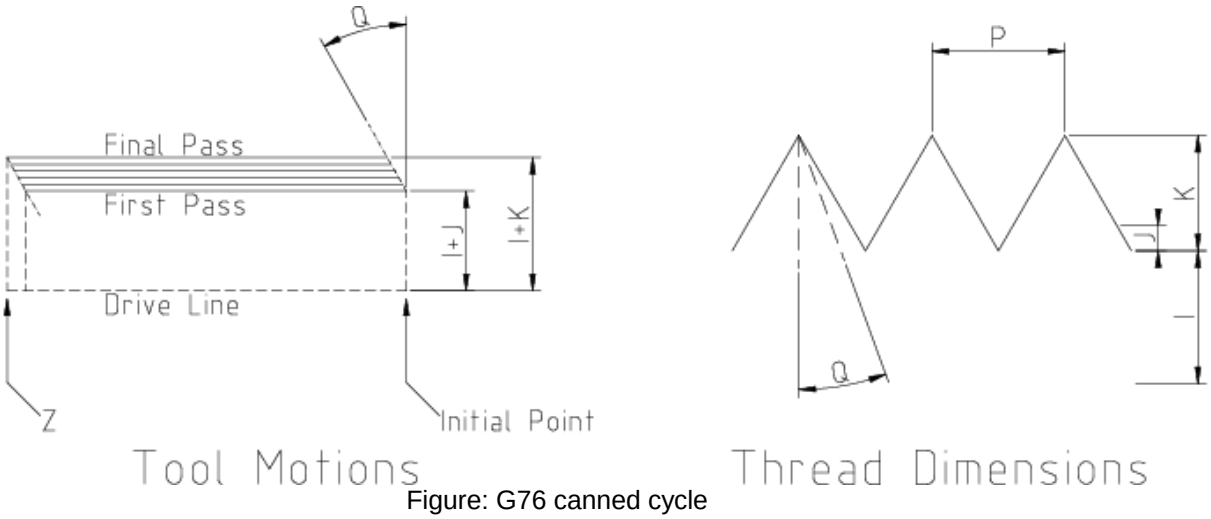


Figure: G76 canned cycle

This is how it works:

1) Before the start, the spindle rate is measured.

2) The feed for de z-axis is calculated: F = pitch * spindleRate

3) The CPU programmed such that a movement is started on the spindle pulse.

4) The movement is calculated and send to the CPU.

5) The movement is started when the spindle pulse passes.

6) Before the treading starts, the spindle-rate is measured, averaged and the feed is calculated from this.

Not that the inside and outside thread diameter are determined by the start position, the position before G76 and the I, K parameters.

3.5.18 Cancel Modal Motion - G80

Program G80 to ensure no axis motion will occur.

It is an error if:

- Axis words are programmed when G80 is active, unless a modal group 0 G code is programmed which uses axis words.

3.5.19 Canned Cycles - G81 to G89

The canned cycles G81 through G89 have been implemented as described in this section. Two examples are given with the description of G81 below.

All canned cycles are performed with respect to the currently selected plane. Any of the three planes (XY, YZ, and ZX) may be selected. Throughout this section, most of the descriptions assume the XY-plane has been selected. The behavior is always analogous if the YZ or XZ-plane is selected.

Rotational axis words are allowed in canned cycles, but it is better to omit them. If rotational axis words are used, the numbers must be the same as the current position numbers so that the rotational axes do not move.

All canned cycles use X, Y, R, and Z numbers in the NC code. These numbers are used to determine X, Y, R, and Z positions. The R (usually meaning retract) position is along the axis perpendicular to the currently selected plane (Z-axis for XY-plane, X-axis for YZ-plane, Y-axis for XZ-plane). Some canned cycles use additional arguments.

For canned cycles, we will call a number "sticky" if, when the same cycle is used on several lines of code in a row, the number must be used the first time, but is optional on the rest of the lines. Sticky numbers keep their value on the rest of the lines if they are not explicitly programmed to be different. The R number is always sticky.

In incremental distance mode: when the XY-plane is selected, X, Y, and R numbers are treated as increments to the current position and Z as an increment from the Z-axis position before the move involving Z takes place; when the YZ or XZ-plane is selected, treatment of the axis words is analogous. In absolute distance mode, the X, Y, R, and Z numbers are absolute positions in the current coordinate system.

The L number is optional and represents the number of repeats. L=0 is not allowed. If the repeat feature is used, it is normally used in incremental distance mode, so that the same sequence of motions is repeated in several equally spaced places along a straight line. In

absolute distance mode, L > 1 means "do the same cycle in the same place several times," Omitting the L word is equivalent to specifying L=1. The L number is not sticky.

When L>1 in incremental mode with the XY-plane selected, the X and Y positions are determined by adding the given X and Y numbers either to the current X and Y positions (on the first go-around) or to the X and Y positions at the end of the previous go-around (on the repetitions). The R and Z positions do not change during the repeats.

The height of the retract move at the end of each repeat (called "clear Z" in the descriptions below) is determined by the setting of the retract mode: either to the original Z position (if that is above the R position and the retract mode is G98, OLD_Z), or otherwise to the R position. See Section 3.5.20

It is an error if:

- X, Y, and Z words are all missing during a canned cycle,
- a P number is required and a negative P number is used,
- an L number is used that does not evaluate to a positive integer,
- rotational axis motion is used during a canned cycle,
- inverse time feed rate is active during a canned cycle,
- cutter radius compensation is active during a canned cycle.

When the XY plane is active, the Z number is sticky, and it is an error if:

- the Z number is missing and the same canned cycle was not already active,
- the R number is less than the Z number.

When the XZ plane is active, the Y number is sticky, and it is an error if:

- the Y number is missing and the same canned cycle was not already active,
- the R number is less than the Y number.

When the YZ plane is active, the X number is sticky, and it is an error if:

- the X number is missing and the same canned cycle was not already active,
- the R number is less than the X number.

3.5.19.1 PRELIMINARY AND IN-BETWEEN MOTION

At the very beginning of the execution of any of the canned cycles, with the XY-plane selected, if the current Z position is below the R position, the Z-axis is traversed to the R position. This happens only once, regardless of the value of L.

In addition, at the beginning of the first cycle and each repeat, the following one or two moves are made:

1. a straight traverse parallel to the XY-plane to the given XY-position,
2. a straight traverse of the Z-axis only to the R position, if it is not already at the R position.

If the XZ or YZ plane is active, the preliminary and in-between motions are analogous.

3.5.19.2 G81 CYCLE

The G81 cycle is intended for drilling. Program **G81 X… Y… Z… A… R… L…**

1. Preliminary motion, as described above.
2. Move the Z-axis only at the current feed rate to the Z position.
3. Retract the Z-axis at traverse rate to clear Z.

Example: Suppose the current position is (1, 2, and 3) and the XY-plane has been selected, and the following line of NC code is interpreted.

G90 G81 G98 X4 Y5 Z1.5 R2.8

This calls for absolute distance mode (G90) and OLD_Z retract mode (G98) and calls for the G81 drilling cycle to be performed once. The X number and X position are 4. The Y number and Y position are 5. The Z number and Z position are 1.5. The R number and clear Z are 2.8. Old Z is 3. The following moves take place.

1. a traverse parallel to the XY-plane to (4,5,3)
2. a traverse parallel to the Z-axis to (4,5,2.8)
3. a feed parallel to the Z-axis to (4,5,1.5)
4. a traverse parallel to the Z-axis to (4,5,3)

Example: Suppose the current position is (1, 2, and 3) and the XY-plane has been selected, and the following line of NC code is interpreted.

G91 G81 G98 X4 Y5 Z-0.6 R1.8 L3

This calls for incremental distance mode (G91) and OLD_Z retract mode (G98) and calls for the G81 drilling cycle to be repeated three times. The X number is 4, the Y number is 5, the Z number is -0.6 and the R number is 1.8. The initial X position is 5 (=1+4), the initial Y position is 7 (=2+5), the clear Z position is 4.8 (=1.8+3), and the Z position is 4.2 (=4.8-0.6). Old Z is 3. The first move is a traverse along the Z-axis to (1,2,4.8), since old Z < clear Z.
The first repeat consists of 3 moves.

1. a traverse parallel to the XY-plane to (5,7,4.8)
2. a feed parallel to the Z-axis to (5,7, 4.2)
3. a traverse parallel to the Z-axis to (5,7,4.8)

The second repeat consists of 3 moves. The X position is reset to 9 (=5+4) and the Y position to 12 (=7+5).

1. a traverse parallel to the XY-plane to (9,12,4.8)
2. a feed parallel to the Z-axis to (9,12, 4.2)
3. a traverse parallel to the Z-axis to (9,12,4.8)

The third repeat consists of 3 moves. The X position is reset to 13 (=9+4) and the Y position to 17 (=12+5).

1. a traverse parallel to the XY-plane to (13,17,4.8)
2. a feed parallel to the Z-axis to (13,17, 4.2)
3. a traverse parallel to the Z-axis to (13,17,4.8)

3.5.19.3 G82 CYCLE

The G82 cycle is intended for drilling. Program **G82 X… Y… Z… A… R… L… P…**

1. Preliminary motion, as described above.
2. Move the Z-axis only at the current feed rate to the Z position.
3. Dwell for the P number of seconds.
4. Retract the Z-axis at traverse rate to clear Z.

3.5.19.4 G83 CYCLE

The G83 cycle (often called peck drilling) is intended for deep drilling or milling with chip breaking. The retracts in this cycle clear the hole of chips and cut off any long stringers (which are common when drilling in aluminum). This cycle takes a Q number which represents a "delta" increment along the Z-axis**. Program G83 X… Y… Z… A… R… L… Q…**

1. Preliminary motion, as described above.
2. Move the Z-axis only at the current feed rate downward by delta or to the Z position, whichever is less deep.
3. Rapid back out to the clear_z.
4. Rapid back down to the current hole bottom, backed off a bit.
5. Repeat steps 1, 2, and 3 until the Z position is reached at step 1.
6. Retract the Z-axis at traverse rate to clear Z.

It is an error if:
• the Q number is negative or zero.

3.5.19.5 G85 CYCLE

The G85 cycle is intended for boring or reaming, but could be used for drilling or milling.
Program G85 X… Y… Z… A… B… C… R… L…
Preliminary motion, as described above.
Move the Z-axis only at the current feed rate to the Z position.
Retract the Z-axis at the current feed rate to clear Z.

3.5.19.6 G86 CYCLE

The G86 cycle is intended for boring. This cycle uses a P number for the number of seconds to dwell. Program G86 X… Y… Z… A… B… C… R… L… P…
Preliminary motion, as described above.
Move the Z-axis only at the current feed rate to the Z position.
Dwell for the P number of seconds.
Stop the spindle turning.
Retract the Z-axis at traverse rate to clear Z.
Restart the spindle in the direction it was going.

The spindle must be turning before this cycle is used. It is an error if:
the spindle is not turning before this cycle is executed.

3.5.19.7 G87 CYCLE

The G87 cycle is intended for back boring.
Program **G87 X… Y… Z… A… R… L… I… J… K…**

The situation, as shown in Figure 3-1, is that you have a through hole and you want to counter bore the bottom of hole. To do this you put an L-shaped tool in the spindle with a cutting surface on the UPPER side of its base. You stick it carefully through the hole when it is not spinning and is oriented so it fits through the hole, then you move it so the stem of the L is on the axis of the hole, start the spindle, and feed the tool upward to make the counter bore. Then you stop the tool, get it out of the hole, and restart it.

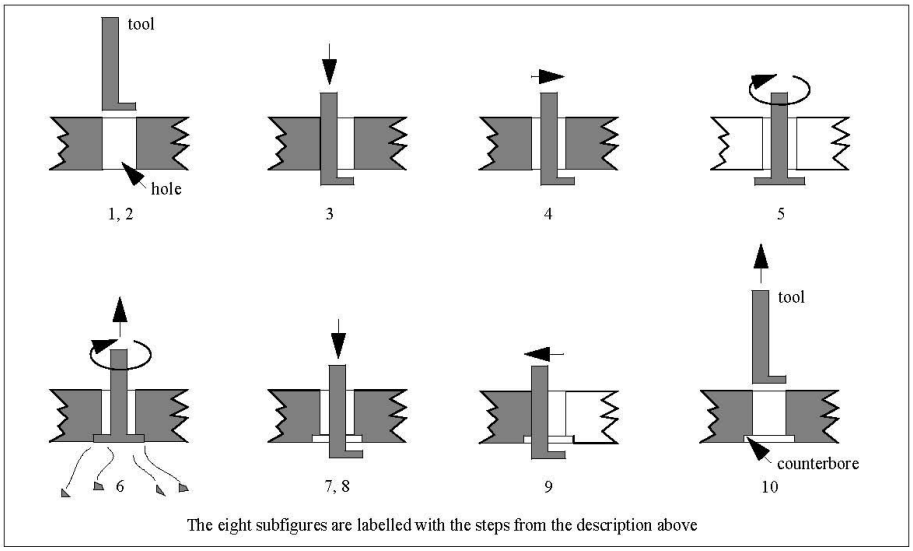
This cycle uses I and J numbers to indicate the position for inserting and removing the tool. I and J will always be increments from the X position and the Y position, regardless of the distance mode setting. This cycle also uses a K number to specify the position along the Z-axis of the controlled point top of the counter bore. The K number is a Z-value in the current coordinate system in absolute distance mode, and an increment (from the Z position) in incremental distance mode.

1. Preliminary motion, as described above.
2. Move at traverse rate parallel to the XY-plane to the point indicated by I and J.
3. Stop the spindle in a specific orientation.
4. Move the Z-axis only at traverse rate downward to the Z position.
5. Move at traverse rate parallel to the XY-plane to the X,Y location.
6. Start the spindle in the direction it was going before.
7. Move the Z-axis only at the given feed rate upward to the position indicated by K.
8. Move the Z-axis only at the given feed rate back down to the Z position.
9. Stop the spindle in the same orientation as before.
10. Move at traverse rate parallel to the XY-plane to the point indicated by I and J.
11. Move the Z-axis only at traverse rate to the clear Z.

12. Move at traverse rate parallel to the XY-plane to the specified X,Y location.
13. Restart the spindle in the direction it was going before.

When programming this cycle, the I and J numbers must be chosen so that when the tool is stopped in an oriented position, it will fit through the hole. Because different cutters are made differently, it may take some analysis and/or experimentation to determine appropriate values for I and J.

Figure 3-1 **G87 Cycle**



3.5.19.8 G88 CYCLE

The G88 cycle is intended for boring. This cycle uses a P word, where P specifies the number of seconds to dwell. Program **G88 X… Y… Z… A… R… L… P…**
Preliminary motion, as described above.

1. Move the Z-axis only at the current feed rate to the Z position.
2. Dwell for the P number of seconds.
3. Stop the spindle turning.
4. Stop the program so the operator can retract the spindle manually.
5. Restart the spindle in the direction it was going.

3.5.19.9 G89 CYCLE

The G89 cycle is intended for boring. This cycle uses a P number, where P specifies the number of seconds to dwell. program **G89 X… Y… Z… A… R… L… P…**

1. Preliminary motion, as described above.
2. Move the Z-axis only at the current feed rate to the Z position.
3. Dwell for the P number of seconds.
4. Retract the Z-axis at the current feed rate to clear Z.

3.5.20 Set Distance Mode - G90 and G91

To make the current point have the coordinates you want (without motion), program G92 X…
Interpretation of RS274/NGC code can be in one of two distance modes: absolute or incremental.

To go into absolute distance mode, program G90. In absolute distance mode, axis numbers (X, Y, Z, A, B, C) usually represent positions in terms of the currently active coordinate system. Any exceptions to that rule are described explicitly in this Section 3.5.

To go into incremental distance mode, program G91. In incremental distance mode, axis numbers (X, Y, Z, A, B, C) usually represent increments from the current values of the numbers.

I and J numbers always represent increments, regardless of the distance mode setting. K numbers represent increments in all but one usage (see Section 3.5.16.8), where the meaning changes with distance mode.

3.5.21 Coordinate System Offsets - G92, G92.1, G92.2, G92.3

To make the current point have the coordinates you want (without motion), program **G92 X… Y… Z… A…** , where the axis words contain the axis numbers you want. All axis words are optional, except that at least one must be used. If an axis word is not used for a given axis, the coordinate on that axis of the current point is not changed.

It is an error if:

- all axis words are omitted.

When G92 is executed, the origin of the currently active coordinate system moves. To do this, origin offsets are calculated so that the coordinates of the current point with respect to the moved origin are as specified on the line containing the G92. In addition, parameters 5211 to 5216 are set to the X, Y, Z, A, B, and C-axis offsets. The offset for an axis is the amount the origin must be moved so that the coordinate of the controlled point on the axis has the specified value.

Here is an example. Suppose the current point is at X=4 in the currently specified coordinate system and the current X-axis offset is zero, then G92 x7 sets the X-axis offset to -3, sets parameter 5211 to -3, and causes the X-coordinate of the current point to be 7.

The axis offsets are always used when motion is specified in absolute distance mode using any of the nine coordinate systems (those designated by G54 - G59.3). Thus all nine coordinate systems are affected by G92.

Being in incremental distance mode has no effect on the action of G92.

Non-zero offsets may already be in effect when the G92 is called. If this is the case, the new value of each offset is A+B, where A is what the offset would be if the old offset were zero, and B is the old offset. For example, after the previous example, the X-value of the current point is 7. If G92 x9 is then programmed, the new X-axis offset is -5, which is calculated by [[7-9] + -3].

To reset axis offsets to zero, program **G92.1** or **G92.2**. G92.1 sets parameters 5211 to 5216 to zero, whereas G92.2 leaves their current values alone.
To set the axis offset values to the values given in parameters 5211 to 5216, program **G92.3**.

You can set axis offsets in one program and use the same offsets in another program. Program G92 in the first program. This will set parameters 5211 to 5216. Do not use G92.1 in the remainder of the first program. The parameter values will be saved when the first program exits and restored when the second one starts up. Use G92.3 near the beginning of the second program. That will restore the offsets saved in the first program. If other programs are to run between the program that sets the offsets and the one that restores them, make a copy of the parameter file written by the first program and use it as the parameter file for the second program.

3.5.22 Set Feed Rate Mode - G93 and G94

Two feed rate modes are recognized: units per minute and inverse time. Program G94 to start the units per minute mode. Program G93 to start the inverse time mode.

In units per minute feed rate mode, an F word (no, not that F word; we mean feed-rate) is interpreted to mean the controlled point should move at a certain number of inches per minute, millimeters per minute, or degrees per minute, depending upon what length units are being used and which axis or axes are moving.

In inverse time feed rate mode, an F word means the move should be completed in [one divided by the F number] minutes. For example, if the F number is 2.0, the move should be completed in half a minute.

When the inverse time feed rate mode is active, an F word must appear on every line which has a G1, G2, or G3 motion, and an F word on a line that does not have G1, G2, or G3 is ignored. Being in inverse time feed rate mode does not affect G0 (rapid traverse) motions.

It is an error if:

- inverse time feed rate mode is active and a line with G1, G2, or G3 (explicitly or implicitly) does not have an F word.

3.5.23 Set Canned Cycle Return Level - G98 and G99

When the spindle retracts during canned cycles, there is a choice of how far it retracts:
(1) retract perpendicular to the selected plane to the position indicated by the R word, or
(2) retract perpendicular to the selected plane to the position that axis was in just before the canned cycle started (unless that position is lower than the position indicated by the R word, in which case use the R word position).

To use option (1), program G99. To use option (2), program G98. Remember that the R word has different meanings in absolute distance mode and incremental distance mode.

3.6 INPUT M CODES

M codes of the RS274/NGC language are shown in Table 3-6

Table 3-6 **M Codes**

M Code	Meaning
M0	program stop
M1 M2	optional program stop
M3 M4	program end
M5 M6	turn spindle clockwise
M7 M8	turn spindle counterclockwise
M9 M30	stop spindle turning
M48	tool change
M49	mist coolant on
M60	flood coolant on
	mist and flood coolant off
	program end, pallet shuttle, and reset
	enable speed and feed overrides
	disable speed and feed overrides
	pallet shuttle and program stop
M64	set general purpose output
M65	clear general purpose output
M66	read general purpose input

3.6.1 Program Stopping and Ending - M0, M1, M2, M30, M60

To stop a running program temporarily (regardless of the setting of the optional stop switch), program **M0 or M1**. If a program is stopped by an M0, M1, or M60, pressing the cycle start button will restart the program at the following line, so the program will continue.
To end a program, program **M2**.
program **M30** for next effects:

- Selected plane is set to CANON_PLANE_XY (like G17).

- Distance mode is set to MODE_ABSOLUTE (like G90).
- Feed rate mode is set to UNITS_PER_MINUTE (like G94).
- Feed and speed overrides are set to ON (like M48).
- Cutter compensation is turned off (like G40).
- The spindle is stopped (like M5).
- The current motion mode is set to G_1 (like G1).
- Coolant is turned off (like M9).
- Note that the coordinate system are no longer reset, I modified this behavior because I have broken a lot of bits due to this so I modified it.

No more lines of code in an RS274/NGC file will be executed after the M2 or M30 command is executed. Pressing cycle start will start the program back at the beginning of the file.

3.6.2 Spindle Control - M3, M4, M5

To start the spindle turning clockwise at the currently programmed speed, program **M3**.
To start the spindle turning counterclockwise at the currently programmed speed, program **M4**.
To stop the spindle from turning, program **M5**.
It is OK to use M3 or M4 if the spindle speed is set to zero. If this is done (or if the speed override switch is enabled and set to zero), the spindle will not start turning. If, later, the spindle speed is set above zero (or the override switch is turned up), the spindle will start turning. It is OK to use M3 or M4 when the spindle is already turning or to use M5 when the spindle is already stopped.

3.6.3 Tool Change -M6

To change a tool in the spindle from the tool currently in the spindle to the tool most recently selected (using a T word - see Section 3.7.3), program **M6**. When the tool change is complete:

- The spindle will be stopped.
- The tool that was selected (by a T word on the same line or on any line after the previous tool change) will be in the spindle. The T number is an integer giving the changer slot of the tool (not its id).
- If the selected tool was not in the spindle before the tool change, the tool that was in the spindle (if there was one) will be in its changer slot.
- The coordinate axes will be stopped in the same absolute position they were in before the tool change (but the spindle may be re-oriented).
- No other changes will be made. For example, coolant will continue to flow during the tool change unless it has been turned off by an M9.

The tool change may include axis motion while it is in progress. It is OK (but not useful) to program a change to the tool already in the spindle. It is OK if there is no tool in the selected slot; in that case, the spindle will be empty after the tool change. If slot zero was last selected, there will definitely be no tool in the spindle after a tool change.

The tool change command will call the change_tool subroutine inside macro.cnc.
You can adapt the behavior for your own needs in this function e.g:

- Perform automatic tool-length measurement
- Perform tool change with an automatic tool changer.

This is (non functional) example of how to implement automatic tool change for a 4-tool changer. It checks whether current tool is already in the spindle. It check that the tool number is in range of 1-4. Then it first drops current tool and picks the new tool:

```
;*************************************
;* This is file macro.cnc
;* It is automatically loaded
;* Modify this file to define your own toolchange sequence
```

```
;* M6 T1 in you program will do a gosub to this function when it exists
;* #5008 contains current tool number, 0 is none
;* #5011 contains new tool number
;*
;* You may also add frequently used macro's in this file.
;**************************************

;This example shows how to make your own tool_changer work.
;It is made for 4 tools
;First current tool is dropped, then the new tool is picked
;There is a check whether selected tool is already in the spindle
;Also a check that the tool is within 1-4
;There is a picktool subroutine for each tool and a droptool subroutine for
each tool.
;These routines need to be moddified to fit your machine and tool changer

sub change_tool
    ;Use #1000 to indicate successfull toolchange
      #1000 = 0 ; Tool change not performed

    if [ [#5011] == [#5008] ]
       msg "Tool already in spindle"
    endif

    ; check tool in spindle and exit sub
    If [ [#5011] <> [#5008] ]
        if [[#5011] > 4 ]
            msg "Please select a tool from 1 to 4."
            m0 ; stop
        else
           ;Drop current tool
           If [[#5008] == 1]
                GoSub DropTool1
            endif

            If [[#5008] == 2]
                GoSub DropTool2
            endif

            If [[#5008] == 3]
                GoSub DropTool3
            endif

            If [[#5008] == 4]
                GoSub DropTool4
            endif

            ;Pick new tool
            if [[#5011] == 1]
                GoSub PickTool1
            endif

            if [[#5011] == 2]
                GoSub PickTool2
            endif

            if [[#5011] == 3]
                GoSub PickTool3
            endif

            if [[#5011] == 4]
                GoSub PickTool4
            endif
        endif
    endif

    If [[#1000] == 1]
        msg "Tool change successfull, tool "#5008" Replaced by tool "#5011
        m6t[#5011]
    endif

EndSub
```

```
;Pick tool subroutines
Sub PickTool1
    msg "Picking tool 1"
    ;Toggle AUX output
    M82
    G4P1
    M83
    G0x10
    G0x0
    #1000 = 1 ; toolchange success
endsub

Sub PickTool2
    msg "Picking tool 2"
    ;Toggle AUX output
    M82
    G4P1
    M83
    G0x20
    G0x0
    #1000 = 1 ; Tool change success
endsub

Sub PickTool3
    msg "Picking tool 3"
    ;Toggle AUX output
    M82
    G4P1
    M83
    G0x30
    G0x0
    #1000 = 1 ; Tool change success
endsub

Sub PickTool4
    msg "Picking tool 4"
    ;Toggle AUX output
    M82
    G4P1
    M83
    G0x40
    G0x0
    #1000 = 1 ; Tool change success
endsub

;Drop tool subroutines
Sub DropTool1
    msg "Dropping tool 1"
    G0x10
    G0y10
endsub

Sub DropTool2
    msg "Dropping tool 2"
    G0x20
    G0y10
endsub

Sub DropTool3
    msg "Dropping tool 3"
    G0x30
    G0y30
endsub

Sub DropTool4
    msg "Dropping tool 4"
    G0x40
    G0y40
endsub
```

3.6.4 Coolant Control - M7, M8, M9

To turn mist coolant on, program M7. To turn flood coolant on, program M8. To turn all coolant off, program M9. It is always OK to use any of these commands, regardless of what coolant is on or off.

3.6.5 Override Control - M48 and M49

To enable the speed and feed override switches, program M48. To disable both switches, program M49. See Section 2.2.1 for more details. It is OK to enable or disable the switches when they are already enabled or disabled.

3.6.6 IO Functions

To control the outputs, these functions have been added besides the standard M-Functions/

Standard, according to [NIST]
M3 PWM according S value, PWMON = on
M4 PWM according S value, PWMON = off
M5 PWM off, PWMON off.
M7 Mist on
M8 Flood on
M9 Mist/Flood off

Additional, to support the features of the USBCNC CPU's
M80 drive enable on
M81 drive enable off
M82/M61 Aux1 on
M83/M62 Aux1 off
M84 PWMON on
M85 PWMON off
M86 PWM according S value (s/s-max from setup * 100%)
M87 PWM off

General purpose IO (Advantronix USB I/O card)

M64 Px
Set output x on gpio card.

M64 Ex Qy
Set PWM output x on gpio card to value y (0 <= y <= 100)

M65 Px
Clear output x on gpio card.

M66 Px
Read digital input x.

M66 Px Ly Qx.xx
Read digital input and specify wait mode
Px: x is input number
L0: do not wait
L1: Wait mode Rise
L2: Wait mode Fall
L3: Wait mode High
L4: Wait mode Low
Qx: x is timeout

M66 Ex Ly Qx.xx
==========

Read analogue input and specify wait mode
Px: x is input number
L0: do not wait
L1: Wait mode Rise (Not yet implemented)
L2: Wait mode Fall (Not yet implemented)
L3: Wait mode High
L4: Wait mode Low
Qx: x is timeout

For all M66 variants, the input value is stored into #5399

3.7 OTHER INPUT CODES

3.7.1 Set Feed Rate - F

To set the feed rate, program F… . The application of the feed rate is as described in Section 2.1.2.5, unless inverse time feed rate mode is in effect, in which case the feed rate is as described in Section 3.5.19.

3.7.2 Set Spindle Speed - S

To set the speed in revolutions per minute (rpm) of the spindle, program S… . The spindle will turn at that speed when it has been programmed to start turning. It is OK to program an S word whether the spindle is turning or not. If the speed override switch is enabled and not set at 100%, the speed will be different from what is programmed. It is OK to program S0; the spindle will not turn if that is done.
The CPU's that support PWM output will have its PWM value set conform the requested spindle speed if the spindle is turned on.

It is an error if:

- the S number is negative.

As described in Section 3.5.16.5, if a G84 (tapping) canned cycle is active and the feed and speed override switches are enabled, the one set at the lower setting will take effect. The speed and feed rates will still be synchronized. In this case, the speed may differ from what is programmed, even if the speed override switch is set at 100%.

3.7.3 Select Tool - T

To select a tool, program T…, where the T number is the carousel slot for the tool. The tool is not changed until an M6 is programmed (see Section 3.6.3). The T word may appear on the same line as the M6 or on a previous line. It is OK, but not normally useful, if T words appear on two or more lines with no tool change. The carousel may move a lot, but only the most recent T word will take effect at the next tool change. It is OK to program T0; no tool will be selected. This is useful if you want the spindle to be empty after a tool change.

It is an error if:

- a negative T number is used,
- a T number larger than the number of slots in the carousel is used.

On some machines, the carousel will move when a T word is programmed, at the same time machining is occurring. On such machines, programming the T word several lines before a tool change will save time. A common programming practice for such machines is to put the T word for the next tool to be used on the line after a tool change. This maximizes the time available for the carousel to move.

3.8 ORDER OF EXECUTION

The order of execution of items on a line is critical to safe and effective machine operation. Items are executed in the order shown in Table 3-7 if they occur on the same line.

Table 3-7 Order of execution

1. comment (includes message).
2. set feed rate mode (G93, G94 -inverse time or per minute).
3. set feed rate (F).
4. set spindle speed (S).
5. select tool (T).
6. change tool (M6).
7. spindle on or off (M3, M4, M5).
8. coolant on or off (M7, M8, M9).
9. enable or disable overrides (M48, M49).
10. dwell (G4).
11. set active plane (G17, G18, G19).
12. set length units (G20, G21).
13. cutter radius compensation on or off (G40, G41, G42)
14. cutter length compensation on or off (G43, G49)
15. coordinate system selection (G54, G55, G56, G57, G58, G59, G59.1, G59.2, G59.3).
16. set path control mode (G61, G61.1, G64)
17. set distance mode (G90, G91).
18. set retract mode (G98, G99).
19. home (G28, G30) or change coordinate system data (G10) or set axis offsets (G92, G92.1, G92.2, G94).
20. perform motion (G0 to G3, G80 to G89), as modified (possibly) by G53.
21. stop(M0,M1, M2,M30,M60).

4 Language extensions

To provide additional flexibility, I created some extensions in the language that allow for programming.

4.1 FLOW CONTROL

You can use the following flow control commands in a job:
IF[x]-ELSE-ENDIF constructs to define x dependent execution
WHILE[x]-ENDWHILE constructs to define x dependent repeated execution
SUB <name>-ENDSUB constructs to define a subroutine
GOSUB <name> construct to call a subroutine

4.2 SUPPORTED OPERATIONS ON EXPRESSIONS

4.2.1 unary operations

abs absolute value
acos arc cosine
asin arc sine
atan arc tangent
cos cosine
exp e raised to

fix	round down
fup	round
ln	natural log of
round	round
sin	sine
sqrt	square root
tan	tangent
not	logical not

4.2.2 binary operations:

/	divided by
mod	modulo
**	power
*	times
and	logic and
xor	logic exclusive or
-	minus
or	logic non exclusive or
+	plus
>	greater then
>=	greater than or equal
<	less then
<=	less than or equal
==	is equal
<>	not equal
band	bitwise and
bxor	bitwise exclusive or
bor	bitwise non exclusive or
<<	shift left
>>	shift right

See also B.2 for examples on expressions.

4.2.3 An example:

```
sub do_circle_holes

#1=0
g0 z1 x0 y0
while [#1 <> 360]
      #2 = [10 * sin[#1]]
      #3 = [10 * cos[#1]]
      g0 x[#3] y[#2]
      g1 z-1
      g1 z1
      #1 = [#1 + 30]


      if [#1 == 360]
            msg "Done"
      else
            msg "processing at angle "#1
      endif

endwhile

endsub

gosub do_circle_holes
m30
```

This example drills holes at a circle with a radius of 10, each 30 degrees. The code that performs this is put in a subroutine, which can be called as many times as needed in the main program.

4.2.4 Special interpreter commands, non G-Code

Messages:

```
Msg "Hello there, the value of #1 = "#1" and the value of #2 = "#2
```

ErrMsg

Same as Msg, but this one generates an error

Store position

```
SP <filename> [0 or 1]
```

This command stores the actual position in given file name.
The extra parameter 0 means create the file.
1 means add to existing file.
If only file name is given, the position is added to existing file.

DlgMsg

Gives a dialog message for an interactive g-code program.

```
DlgMsg <dialog message> <par1Name> <par1ParNumber> ... <par7Name> <par7ParNumber>
```

Example:
DlgMsg "Give parameters" par1 100 par2 101
Just try and you will see what this is about.

LogFile, LogMsg

Log anything to a file..

```
LogFile <fileName> <1=append, 0=open new>
LogMsg  your message
```

Example:
LogFile “text.txt” 1
LogMsg “Hi, the current position of X is “#5001

Now check the contents of file text.txt.

4.2.5 Special interpreter MDI commands.

M6 TX which is a tool change will call the subroutine change_tool. This subroutine can be customized to match your machine.

Gosub subname moves the interpreter to the first line off the subroutine, allowing you to execute the subroutine without calling it from the main program. This is good for testing subroutines. In combination with DlgMsg you can give your own input parameters.

4.3 MACRO FILE AND AUTOMATIC TOOL CHANGE

Whenever a G-Code file is loaded, also the file “macro.cnc” is loaded. In this file you may put your frequently used subroutines, these can be invoked by the G-Code file through
GOSUB subroutineName.
The file contains default one special subroutine called “change_tool”, this function is called automatically when a M6 Tx command (Tool change) is encountered in the G-Code file. With this it is possible to define your own tool change, especially useful when you have an automatic tool changer. You can put moves and I/O actions there as well as automatic tool length measurement using the probe with G38.2.

Note: When the macro file is not existing, press “save ini file” in the setup screen, a default macro.cnc file is created, this file is in the main USBCNC directory and cannot be moved to another place.

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A Cutter Radius Compensation

This appendix discusses cutter radius compensation. It is intended for NC programmers and machine operators.

See Section 3.5.10 for additional information on cutter radius compensation.

A.1 INTRODUCTION

The cutter radius compensation capabilities of the Interpreter enable the programmer to specify that a cutter should travel to the right or left of an open or closed contour in the XY-plane composed of arcs of circles and straight line segments.

Cutter radius compensation is performed only with the XY-plane active. All the figures in this appendix, therefore, show projections on the XY-plane.

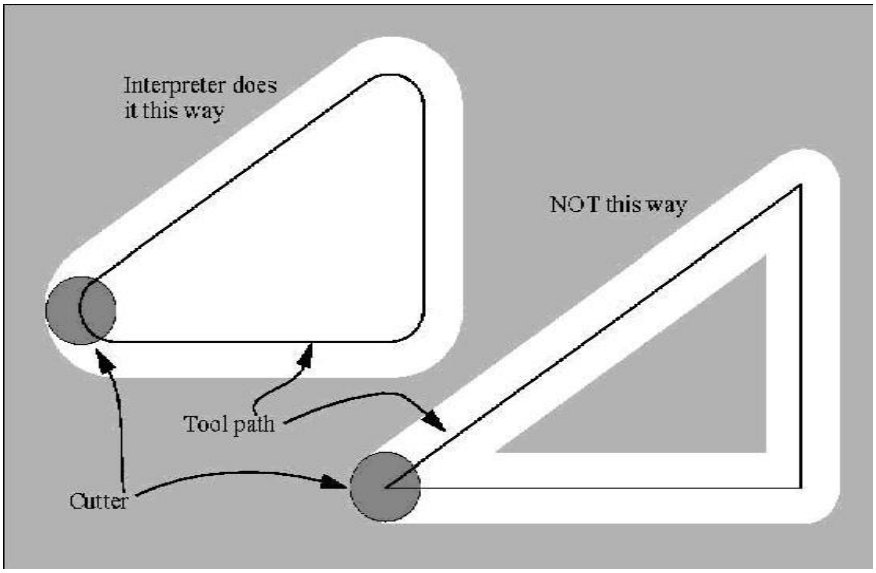
Where the adjacent sides of remaining material meet at a corner, there are two common ways to handle the tool path. The tool may pass in an arc around the corner, or the tool path may continue straight in the direction it was going along the first side until it reaches a point where it changes direction to go straight along the second side. Figure A-1 shows these two types of path. On Figure A-1:

- Uncut material is shaded in the figures. Note that the inner triangles have the same shape with both tool paths.
- The white areas are the areas cleared by the tool.
- The lines in the center of the white areas represent the path of the tip of a cutting tool.
- The tool is the cross-hatched circles.

Both paths will clear away material near the shaded triangle and leave the shaded triangle uncut. When the Interpreter performs cutter radius compensation, the tool path is rounded at the corners, as shown on the left in Figure A-1. In the method on the right (the one not used), the tool does not stay in contact with the shaded triangle at sharp corners, and more material than necessary is removed.

There are also two alternatives for the path that is programmed in NC code during cutter radius compensation. The programmed path may be either (1) the edge of the material to remain uncut (for example, the edge of the inner triangle on the left of Figure A-1), or (2) the nominal tool path (for example, the tool path on the left side of Figure A-1). The nominal tool path is the path that would be used if the tool were exactly the intended size. The Interpreter will handle both cases without being told which one it is. The two cases are very similar, but different enough that they are described in separate sections of this manual. To use the material edge method, read Section A.3. To use the nominal path method, read Section A.4.

Figure A-1



Z-axis motion may take place while the contour is being followed in the XY-plane. Portions of the contour may be skipped by retracting the Z-axis above the part, following the contour to the next point at which machining should be done, and re-extending the Z-axis. These skip motions may be performed at feed rate (G1) or at traverse rate (G0). The Z motion will not interfere with the XY path following. The sample NC code in this appendix does not include moving the Z-axis. In actual programs, include Z-axis motion wherever you want it.

Rotational axis motions (A, B, and C axes) are allowed with cutter radius compensation, but using them would be very unusual.

Inverse time feed rate (G93) or units per minute feed rate (G94) may be used with cutter radius compensation. Under G94, the feed rate will apply to the actual path of the cutter tip, not to the programmed contour.

A.1.1 Data for Cutter Radius Compensation

The Interpreter world model keeps three data items for cutter radius compensation: the setting itself (right, left, or off), program_x, and program_y. The last two represent the X and Y positions which are given in the NC code while compensation is on. When compensation is off, these both are set to a very small number (10-20) whose symbolic value is "unknown". The Interpreter world model uses the data items current_x and current_y to represent the position of the center of the tool tip (in the currently active coordinate system) at all times.

A.2 PROGRAMMING INSTRUCTIONS

A.2.1 Turning Cutter Radius Compensation On

To start cutter radius compensation keeping the tool to the left of the contour, program **G41 D…**. The D word is optional (see "Use of D Number", just below).

To start cutter radius compensation keeping the tool to the right of the contour, program **G42 D…** .

In Figure A-1, for example, if G41 were programmed, the tool would move clockwise around the triangle, so that the tool is always to the left of the triangle when facing in the direction of travel. If G42 were programmed, the tool would stay right of the triangle and move counter clockwise around the triangle.

A.2.2 Turning Cutter Radius Compensation Off

To stop cutter radius compensation, program **G40**. It is OK to turn compensation off when it is already off.

A.2.3 Sequencing

If G40, G41, or G42 is programmed on the same line as tool motion, cutter compensation will be turned on or off before the motion is made. To make the motion come first, the motion must be programmed on a separate, previous line of code.

A.2.4 Use of D Number

Programming a D word with G41 or G42, is optional.
If a D number is programmed, it must be a non-negative integer. It represents the slot number of the tool whose radius (half the diameter given in the tool table) will be used, or it may be zero (which is not a slot number). If it is zero, the value of the radius will also be zero. Any slot in the tool table may be selected. The D number does not have to be the same as the slot number of the tool in the spindle, although it is rarely useful for it not to be.
If a D number is not programmed, the slot number of the tool in the spindle will be used as the D number.

A.3 Material Edge Contour

When the contour is the edge of the material, the outline of the edge is described in the NC program.
For a material edge contour, the value for the diameter in the tool table is the actual value of the diameter of the tool. The value in the table must be positive. The NC code for a material edge contour is the same regardless of the (actual or intended) diameter of the tool.

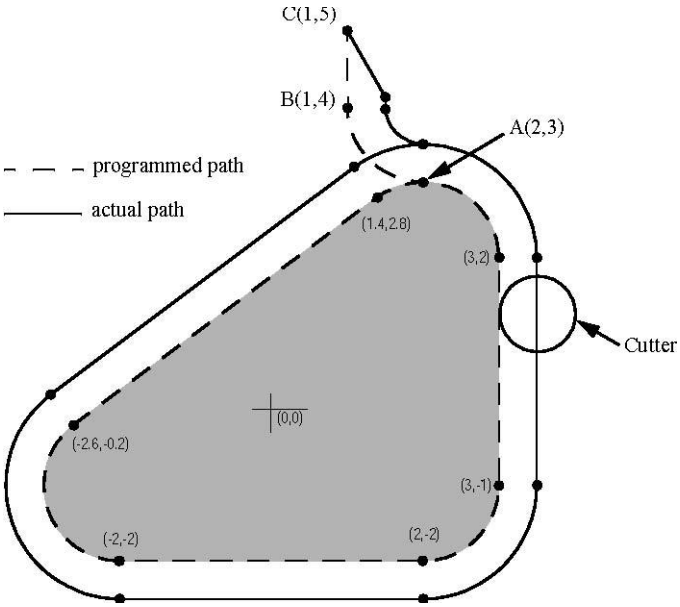
A.3.1 Programming Entry Moves

In general, two pre-entry moves and one entry move are needed to begin compensation correctly. However, if there is a convex corner on the contour, a simpler method is available using zero or one pre-entry move and one entry move. The general method, which will work in all situations, is described first. We assume here that the programmer knows what the contour is already and has the job of adding entry moves.

A.3.1.1 GENERAL METHOD

The general method includes programming two pre-entry moves and one entry move. See Figure A-2. The shaded area is the remaining material. It has no corners, so the simple method cannot be used. The dotted line is the programmed path. The solid line is the actual path of the tool tip. Both paths go clockwise around the remaining material. A cutter one unit in diameter is shown part way around the path. The black dots mark points at the beginning or end of programmed or actual moves. The figure shows the second pre-entry move but not the first, since the beginning point of the first pre-entry move could be anywhere.

Figure A-2, Cutting radius compensation entry moves (for material edge contour)



First, pick a point A on the contour where it is convenient to attach an entry arc. Specify an arc outside the contour which begins at a point B and ends at A tangent to the contour (and going in the same direction as it is planned to go around the contour). The radius of the arc should be larger than half the diameter given in the tool table. Then extend a line tangent to the arc from B to some point C, located so that the line BC is more than one tool radius long. After the construction is finished, the code is written in the reverse order from the construction. The NC code is shown in Table A-1; the first three lines are the entry moves just described.

Table A-1 NC program for figure A-2

N0010 G1 X1 Y5 (make first pre-entry move to C)
N0020 G41 G1 Y4 (turn compensation on and make second pre-entry move to point B)
N0030 G3 X2 Y3 I1 (make entry move to point A)
N0040 G2 X3 Y2 J-1 (cut along arc at top)
N0050 G1 Y-1 (cut along right side)
N0060 G2 X2 Y-2 I-1 (cut along arc at bottom right)
N0070 G1 X-2 (cut along bottom side)
N0080 G2 X-2.6 Y0.2 J1 (cut along arc at bottom left)
N0090 G1 X1.4 Y2.8 (cut along third side)
N0100 G2 X2 Y3 I0.6 J-0.8 (cut along arc at top of tool path)
N0110 G40 (turn compensation off)

Cutter radius compensation is turned on after the first pre-entry move and before the second pre-entry move (including G41 on the same line as the second pre-entry move turns compensation on before the move is made). In the code above, line N0010 is the first pre-entry move, line N0020 turns compensation on and makes the second pre-entry move, and line N0030 makes the entry move.

A.3.1.2 SIMPLE METHOD

If there is a convex (sticking out, not in) corner somewhere on the contour, a simpler method of making an entry is available. See Figure A-3.

First, pick a convex corner. There is only one corner in Figure A-3. It is at A, and it is convex. Decide which way you want to go along the contour from A. In our example we are keeping the tool to the left of the remaining material and going clockwise. Extend the side to be cut (DA in the figure) to divide the area outside the material near A into two regions; DA extended is

the dotted line AC on the figure. Make a pre-entry move to anywhere in the region on the same side of DC as the remaining material (point B on the figure) and not so close to the remaining material that the tool is cutting into it. Anywhere in the diagonally shaded area of the figure (or above or to the left of that area) is OK. If the tool is already in region, no pre-entry move is needed. Write a line of NC code to move to B, if necessary. Then write a line of NC code for a straight entry move that turns compensation on and goes to point A.
If B is at (1.5, 4), the two lines of code for the pre-entry and entry moves would be:

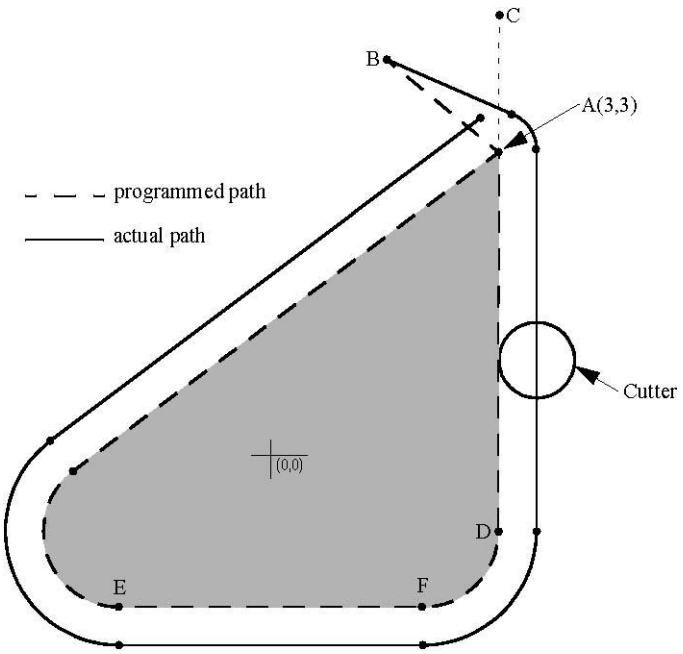
N0010 G1 X1.5 Y4 (move to B)
N0020 G41 G1 X3 Y3 (turn compensation on and make entry move to A)

These two lines would be followed by four lines identical to lines N0050 to N0080 from Table A-1, but the end of the program would be different since the shape of remaining material is different.

It would be OK for B to be on line AC. In fact, B could be placed on the extension outside the part of any straight side of the part. B could be placed on EF extended to the right (but not to the left, for going clockwise), for example.

If DA were an arc, not a straight line, the two lines of code above would still be suitable. In this case, the dotted line extending DA should be tangent to DA at A.
Figure A-3 Simpler cutter radius compensation entry move (for material edge contour)

Figure A-3 Simpler compensation entry move



A.4 NOMINAL PATH CONTOUR

When the contour is a nominal path contour (the path a tool with exactly the intended diameter would take), the tool path is described in the NC program. It is expected that (except for during the entry moves) the path is intended to create some part geometry. The path may be generated manually or by a post-processor, considering the part geometry which is intended to be made. For the Interpreter to work, the tool path must be such that the tool stays in contact with the edge of the part geometry, as shown on the left side of Figure A-1. If a path of the sort shown on the right of Figure A-1 is used, in which the tool does not stay in contact with the part geometry all the time, the Interpreter will not be able to compensate properly when undersized tools are used. A nominal path contour has no corners, so the simple method just described will not work.

For a nominal path contour, the value for the cutter diameter in the tool table will be a small positive number if the selected tool is slightly oversized and will be a small negative number if the tool is slightly undersized. If a cutter diameter value is negative, the Interpreter compensates on the other side of the contour from the one programmed and uses the absolute value of the given diameter. If the actual tool is the correct size, the value in the table should be zero. Suppose, for example, the diameter of the cutter currently in the spindle is 0.97, and the diameter assumed in generating the tool path was 1.0. Then the value in the tool table for the diameter for this tool should be -0.03.

The nominal tool path needs to be programmed so that it will work with the largest and smallest tools expected to be actually used. We will call the difference between the radius of the largest expected tool and the intended radius of the tool the "maximum radius difference." This is usually a small number.

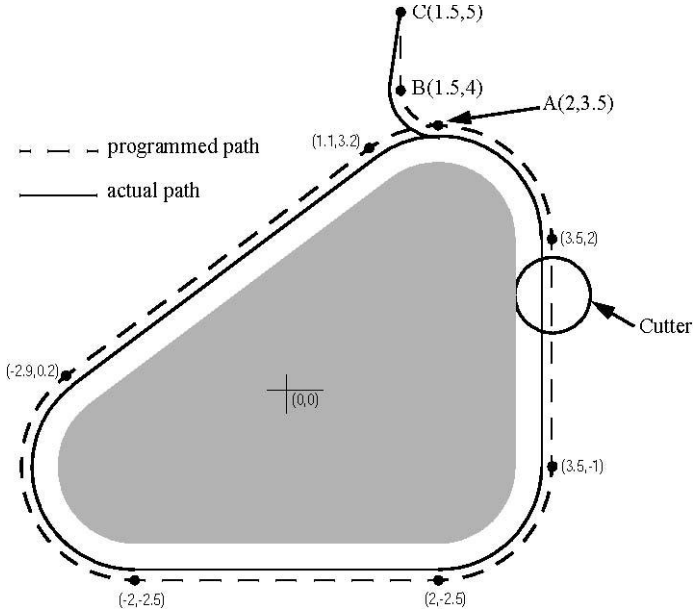
The method includes programming two pre-entry moves and one entry moves. See Figure A-4. The shaded area is the remaining material. The dashed line is the programmed tool path. The solid line is the actual path of the tool tip. Both paths go clockwise around the remaining material. The actual path is to the right of the programmed path even though G41 was programmed, because the diameter value is negative. On the figure, the distance between the two paths is larger than would normally be expected. The 1-inch diameter tool is shown part way around the path. The black dots mark points at the beginning or end of programmed moves. The corresponding points on the actual path have not been marked. The actual path will have a very small additional arc near point B unless the tool diameter is exactly the size intended. The figure shows the second pre-entry move but not the first, since the beginning point of the first pre-entry move could be anywhere.

First, pick a point A on the contour where it is convenient to attach an entry arc. Specify an arc outside the contour which begins at a point B and ends at A tangent to the contour (and going in the same direction as it is planned to go around the contour). The radius of the arc should be larger than the maximum radius difference. Then extend a line tangent to the arc from B to some point C, located so that the length of line BC is more than the maximum radius difference. After the construction is finished, the code is written in the reverse order from the construction. The NC code is shown in Table A-2; the first three lines are the entry moves just described.

Table A-2 NC program for Figure A-4

```
N0010 G1 X1.5 Y5 (make first pre-entry move to C)
N0020 G41 G1 Y4 (turn compensation on and make second pre-entry move to point B)
N0030 G3 X2 Y3.5 I0.5 (make entry move to point A)
N0040 G2 X3.5 Y2 J-1.5 (cut along arc at top)
N0050 G1 Y-1 (cut along right side)
N0060 G2 X2 Y-2.5 I-1.5 (cut along arc at bottom right)
N0070 G1 X-2 (cut along bottom side)
N0080 G2 X-2.9 Y0.2 J1.5 (cut along arc at bottom left)
N0090 G1 X1.1 Y3.2 (cut along third side)
N0100 G2 X2 Y3.5 I0.9 J-1.2 (cut along arc at top of tool path)
N0110 G40 (turn compensation off)
```

Figure A-4 Cutter radius compensation entry moves



Cutter radius compensation is turned on after the first pre-entry move and before the second pre-entry move (including G41 on the same line as the second pre-entry move turns compensation on before the move is made). In the code above, line N0010 is the first pre-entry move, line N0020 turns compensation on and makes the second pre-entry move, and line N0030 makes the entry move.

A.5 PROGRAMMING ERRORS AND LIMITATIONS

The Interpreter will issue the following error messages involving cutter radius compensation. In addition to these, there are several bug messages related to cutter compensation, but they should never occur.

1. Cannot change axis offsets with cutter radius comp
2. Cannot change units with cutter radius comp
3. Cannot probe with cutter radius comp on
4. Cannot turn cutter radius comp on out of xy-plane
5. Cannot turn cutter radius comp on when on
6. Cannot use g28 or g30 with cutter radius comp
7. Cannot use g53 with cutter radius comp
8. Cannot use xz-plane with cutter radius comp
9. Cannot use yz-plane with cutter radius comp
10. Concave corner with cutter radius comp
11. Cutter gouging with cutter radius comp
12. D word with no g41 or g42
13. Multiple d words on one line
14. Negative d word tool radius index used
15. Tool radius index too big
16. Tool radius not less than arc radius with comp
17. Two g codes used from same modal group.

Most of these are self-explanatory. For those that require explanation, an explanation is given below.

Changing a tool while cutter radius compensation is on is not treated as an error, although it is unlikely this would be done intentionally. The radius used when cutter radius compensation

was first turned on will continue to be used until compensation is turned off, even though a new tool is actually being used.

A.5.1 Concave Corner and Tool Radius Too Big (10 and 16)

When cutter radius compensation is on, it must be physically possible for a circle whose radius is the half the diameter given in the tool table to be tangent to the contour at all points of the contour. In particular, the Interpreter treats concave corners and concave arcs into which the circle will not fit as errors, since the circle cannot be kept tangent to the contour in these situations. See Figure A-5. This error detection does not limit the shapes which can be cut, but it does require that the programmer specify the actual shape to be cut (or path to be followed), not an approximation. In this respect, the NIST
RS274/NGC Interpreter differs from interpreters used with many other controllers, which often allow these errors silently and either gouge the part or round the corner.

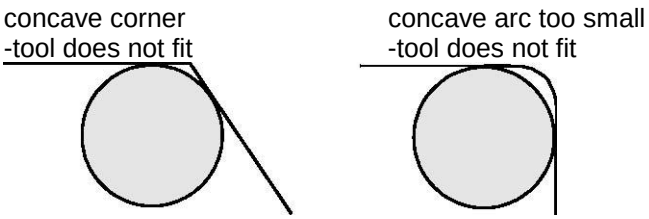


Figure A-5, Two cutter radius compensation errors

In both examples, the line represents a contour, and the circle represents the cross section of a tool following the contour using cutter radius compensation (tangent to one side of the path.)

A.5.2 Cannot Turn Cutter Radius Comp on When On (5)

If cutter radius compensation has already been turned on, it cannot be turned on again. It must be turned off first; then it can be turned on again. It is not necessary to move the cutter between turning compensation off and back on, but the move after turning it back on will be treated as a first move, as described below.
It is not possible to change from one cutter radius index to another while compensation is on because of the combined effect of rules 5 and 12. It is also not possible to switch compensation from one side to another while compensation is on.

A.5.3 Cutter Gouging (11)

If the tool is already covering up the next XY destination point when cutter radius compensation is turned on, the gouging message is given when the line of NC code which gives the point is reached. In this situation, the tool is already cutting into material it should not cut. More details are given in Section A.6.

A.5.4 Tool Radius Index Too Big (15)

If a D word is programmed that is larger than the number of tool carousel slots, this error message is given. In the SAI, the number of slots is 68.

A.5.5 Two G Codes Used from Same Modal Group (17)

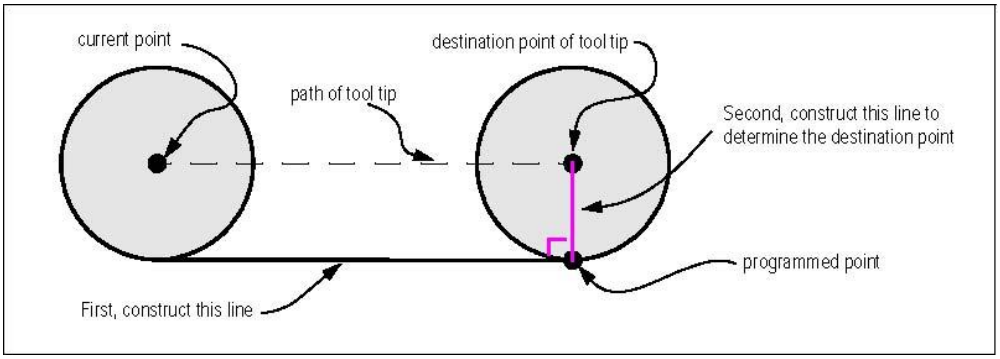
This is a generic message used for many sets of G codes. As applied to cutter radius compensation, it means that more than one of G40, G41, and G42 appears on a line of NC code. This is not allowed.

A.6 First Move into Cutter Compensation

The algorithm used for the first move after cutter radius compensation is turned on, when the first move is a straight line, is to draw a straight line from the programmed destination point which is tangent to a circle whose center is at the current point and whose radius is the radius of the tool. The destination point of the tool tip is then found as the center of a circle of the same radius tangent to the tangent line at the destination point. If the programmed point is inside the initial cross section of the tool (the circle on the left), an error is signaled as described in Section A.5.3. The concept of the algorithm is shown in Figure A-6.

The function that locates the destination point actually takes a computational shortcut based on the fact that the line (not drawn on the figure) from the current point to the programmed point is the hypotenuse of a right triangle having the destination point at the corner with the right angle.

Figure A-6, First cutter radius compensation move - Straight



If the first move after cutter radius compensation has been turned on is an arc, the arc which is generated is derived from an auxiliary arc which has its center at the programmed center point, passes through the programmed end point, and is tangent to the cutter at its current location. If the auxiliary arc cannot be constructed, an error is signaled. The generated arc moves the tool so that it stays tangent to the auxiliary arc throughout the move. This is shown in Figure A-7.

Figure A-7, First cutter radius compensation move - Arc

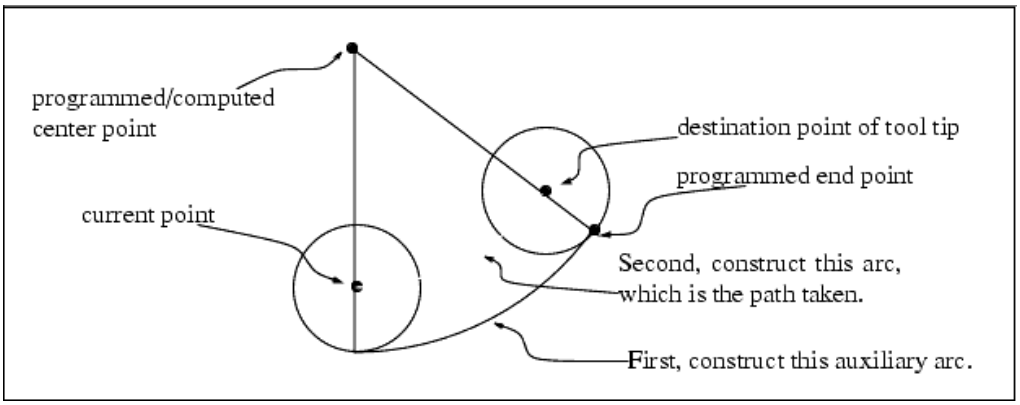


Figure A-7 shows the conceptual approach for finding the arc. The actual computations differ between the center format arc and the radius format arc (see Section 3.5.3).
After the entry moves of cutter radius compensation, the Interpreter keeps the tool tangent to the programmed path on the appropriate side. If a convex corner is on the path, an arc is inserted to go around the corner. The radius of the arc is half the diameter given in the tool table.
When cutter radius compensation is turned off, no special exit move takes place. The next move is what it would have been if cutter radius compensation had never been turned on and the previous move had placed the tool at its current position.

B Sample Programs

This appendix includes three sample programs. This section is intended to be useful to NC programmers and machine operators. Others will probably not find it useful. Additional sample programs are given in Table 3-5 (hole probing), Table A-1 and Table A-2 (cutter radius compensation). Table A-1 and Table A-2 are only sections of programs and need a line at the beginning (to select tool, change tool, start spindle, and set feed and speed rates) and a line at the end (an M2 to end the program).

B.1 SAMPLE SIMPLE PROGRAM

The classical simple computer program prints "Hello world". Here it is in RS274/NGC. The program may be safely run on a machining center.

```
(this program mills "Hello world" between X=0 and X=81 millimeters)
n0010 g21 g0 x0 y0 z50 (top of part should be on XY plane)
n0020 t1 m6 m3 f20 s4000 (use an engraver or small ball-nose end mill)
n0030 g0 x0 y0 z2
n0040 g1 z-0.5 (start H)
n0050 y10
n0060 g0 z2
n0070 y5
n0080 g1 z-0.5
n0090 x 7
n0100 g0 z2
n0110 y0
n0120 g1 z-0.5
n0130 y10
n0140 g0 z2
n0150 x11 y2.5
n0160 g1 z-0.5 (start e)
n0170 x16
n0190 g3 x13.5 y0 i-2.5
n0200 g1 x16
n0210 g0 z2
n0220 x20 y0
n0230 g1 z-0.5 (start l)
n0240 y9
n0250 g0 z2
n0260 x26
n0270 g1 z-0.5 (start l)
n0280 y0
n0290 g0 z2
n0300 x32.5
n0310 g1 z-0.5 (start o)
n0320 g2 x32.5 j2.5
n0330 g0 z2
n0340 x45 y5
n0350 g1 z-0.5 (start w)
n0360 x47 y0n0370 x48.5 y3
n0380 x50 y0n0390 x52 y5
n0400 g0 z2
n0410 x57.5 y0
n0420 g1 z-0.5 (start o)
n0430 g2 x57.5 j2.5
n0440 g0 z2
```

```
n0450 x64
n0460 g1 z-0.5 (start r)
n0470 y5
n0480 y4
n0490 g2 x69 r4
n0500 g0 z2
n0510 x73 y0
n0520 g1 z-0.5 (start l)
n0530 y9 n0540 g0 z2
n0550 x81
n0560 g1 z-0.5 (start d)
n0570 y0
n0580 x79.5
n0590 g2 j2.5 y5
n0600 g1 x81
n0610 g0 z50
n0620 m2
```

B.2 SAMPLE PROGRAM TO TEST EXPRESSIONS

This file is to test the interpretation of expressions. It tests all unary and binary functions implemented. It also tests parameter setting and referencing. The last few lines test more complicated expressions. This program is not intended to be run on a machining center. The tool path is just random back and forth on the X-axis.

```
n0010 g21 g1 x3 f20 (expression test)
n0020 x [1 + 2] (x should be 3)
n0030 x [1 - 2] (x should be -1)
n0040 x [1 --3] (x should be 4)
n0050 x [2/5] (x should be 0.40)
n0060 x [3.0 * 5] (x should be 15)
n0070 x [0 OR 0] (x should be 0)
n0080 x [0 OR 1] (x should be 1)
n0090 x [2 OR 2] (x should be 1)
n0100 x [0 AND 0] (x should be 0)
n0110 x [0 AND 1] (x should be 0)
n0120 x [2 AND 2] (x should be 1)
n0130 x [0 XOR 0] (x should be 0)
n0140 x [0 XOR 1] (x should be 1)
n0150 x [2 XOR 2] (x should be 0)
n0160 x [15 MOD 4.0] (x should be 3)
n0170 x [1 + 2 * 3 - 4 / 5] (x should be 6.2)
n0180 x sin[30] (x should be 0.5)
n0190 x cos[0.0] (x should be 1.0)
n0200 x tan[60.0] (x should be 1.7321)
n0210 x sqrt[3] (x should be 1.7321)
n0220 x atan[1.7321]/[1.0] (x should be 60.0)
n0230 x asin[1.0] (x should be 90.0)
n0240 x acos[0.707107] (x should be 45.0000)
n0250 x abs[20.0] (x should be 20)
n0260 x abs[-1.23] (x should be 1.23)
n0270 x round[-0.499] (x should be 0)
n0280 x round[-0.5001] (x should be -1.0)
n0290 x round[2.444] (x should be 2)
n0300 x round[9.975] (x should be 10)
n0310 x fix[-0.499] (x should be -1.0)
n0320 x fix[-0.5001] (x should be -1.0)
```

n0330 x fix[2.444] (x should be 2)
n0340 x fix[9.975] (x should be 9)
n0350 x fup[-0.499] (x should be 0.0)
n0360 x fup[-0.5001] (x should be 0.0)
n0370 x fup[2.444] (x should be 3)
n0380 x fup[9.975] (x should be 10)
n0390 x exp[2.3026] (x should be 10)
n0400 x ln[10.0] (x should be 2.3026)
n0410 x [2 ** 3.0] #1=2.0 (x should be 8.0)
n0420 ##1 = 0.375 (#1 is 2, so parameter 2 is set to 0.375)
n0430 x #2 (x should be 0.375) #3=7.0
n0440 #3=5.0 x #3 (parameters set in parallel, so x should be 7, not 5)
n0450 x #3 #3=1.1 (parameters set in parallel, so x should be 5, not 1.1)
n0460 x [2 + asin[1/2.1+-0.345] / [atan[fix[4.4] * 2.1 * sqrt[16.8]] /[-18]]**2]n0470 x sqrt[3**2 + 4**2] (x should be 5.0)
n0480 m2

B.3 SAMPLE PROGRAM TO TEST CANNED CYCLES

This file tests canned cycles. It is not intended to be run on a machining center.

n0010 g20 (cycle test)
n0020 g17 g43 h1 m3 s1234 f16 (start in XY-plane)
n0030 g81 x3 y4 r0.2 z-1.1 n0040 x1 y0 r0 g91 l3 (three more g81's an inch apart)
n0050 y-2 r0.1 (one more g81)
n0060 g82 g90 x4 y5 r0.2 z-1.1 p0.6
n0070 x2 z-3.0 (one more G82)
n0080 g91 x-2 y2 r0 l4 (four more g82's)
n0090 g83 g90 x5 y6 r0.2 z-1.1 q0.21
n0100 g84 x6 y7 r0.2 z-1.1
n0110 g85 x7 y8 r0.2 z-1.1
n0120 g86 x8 y9 r0.2 z-1.1 p902.61
n0130 g87 x9 y10 r0.2 z-1.1 i0.231 j-0 k-3
n0135 g91 x1 r0.2 z-1.1 i0.231 j-0 k-3
n0140 g88 x10 y11 r0.2 z-1.1 p0.3333
n0150 g89 x11 y12 r0.2 z-1.1 p1.272
n0160 m4 (run spindle counterclockwise)
n0170 g86 x8 y9 r0.2 z-1.1 p902.61
n0180 g87 x9 y10 r0.2 z-1.1 i0.231 j-0 k-3
n0190 g88 x10 y11 r0.2 z-1.1 p0.3333

n0220 g18 m3 (now run all cycles in the XZ-plane)
n0230 g81 z3 x4 r0.2 y-1.1 n0240 g91 z1 x0 r0 l3
n0260 g82 g90 z4 x5 r0.2 y-1.1 p0.6
n0280 g91 z-2 x2 r0 l4
n0290 g83 g90 z5 x6 r0.2 y-1.1 q0.21
n0300 g84 z6 x7 r0.2 y-1.1
n0310 g85 z7 x8 r0.2 y-1.1
n0320 g86 z8 x9 r0.2 y-1.1 p902.61
n0330 g87 z9 x10 r0.2 y-1.1 k0.231 i-0 j-3
n0335 g91 z1 r0.2 y-1.1 k0.231 i-0 j-3
n0340 g88 z10 x11 r0.2 y-1.1 p0.3333
n0350 g89 z11 x12 r0.2 y-1.1 p1.272
n0420 g19 (now run all cycles in the YZ-plane)
n0430 g81 y3 z4 r0.2 x-1.1
n0440 g91 y1 z0 r0 l3
n0460 g82 g90 y4 z5 r0.2 x-1.1 p0.6

```
n0480 g91 y-2 z2 r0 l4
n0490 g83 g90 y5 z6 r0.2 x-1.1 q0.21
n0500 g84 y6 z7 r0.2 x-1.1
n0510 g85 y7 z8 r0.2 x-1.1
n0520 g86 y8 z9 r0.2 x-1.1 p902.61
n0530 g87 y9 z10 r0.2 x-1.1 j0.231 k-0 i-3
n0535 g91 y1 r0.2 x-1.1 j0.231 k-0 i-3
n0540 g88 y10 z11 r0.2 x-1.1 p0.3333
n0550 g89 y11 z12 r0.2 x-1.1 p1.272
n1000 m2 (the end)
```

B.4 HARDWARE INSTALLATION TIPS

USB is sensitive to EMC noise. Communication problems can occur that result in a buffer-underun and thus a stop of the machine.

To prevent this, the USBCNC CPU should be build in correctly according these general EMC rules:

- Mount all electronics in a metal cabinet or on a metal plate in a plastic cabinet.
- Use a mains filter.
- Create a central GND point near the filter and connect the PE (Protective Earth) as well as the GND from all power supplies to this point.
- Connect the GND point on the green screw connector of CPU4 also to this point.
- Use shielded cables for the motor connections, both inside the cabinet and outside the cabinet. Connect the shield at one side to the central ground point, leave the other side un-connected.
- Use a professional USB2 cable, double shielded with ferrites like this:

- Keep all GND cables especially short and use thick flexible cable
- If not possible to keep it short, then connect it to the metal GND plate.

Here a picture of my own system, it contains various EMC problem makers, like 2 Switched mode power supplies and a frequency inverter for a HF spindle.

Also there a 4 stepper-motor drives working at 75 Volt, motor currents 4,2 Amp.

C Questions and answers

C.1 OPERATION

Q: How do I rewind a job?
A: Press “Reset”